Active Noise Control and its Application for Mitigating Noise through Open Window

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This work is in close collaboration with Prof. Elliott (ISVR) and Prof. Nishimura (n.Lab)
"Noise is an underestimated threat that can cause a number of short- and long-term health problems, such as for example sleep disturbance, cardiovascular effects, poorer work and school performance, hearing impairment,..."
Percentage of persons highly annoyed by aircraft, road, and rail traffic noises. The curves were derived for adults on the basis of surveys (26 for aircraft noise, 19 for road noise, and 8 for railways noise) distributed over 11 countries.

In a meta-analysis, 10 dB reduction in equivalent transportation noise exposure level can be translated to 7-17% decrease in associate health risk (hypertension, heart disease).

What is the Main Contribution of Noise Pollution?

- Road Traffic (125 mil) - 88%
- Rail Traffic (12 mil)
- Air Traffic (4.5 mil)
- Industry (0.3 mil)

Ambient Noise Is “The New Secondhand Smoke”

Excessive ambient noise causes hearing loss; disrupts sleep, function, and communication; and causes nonauditory health effects for millions of people.

Ambient noise is the new secondhand smoke (Fetterman, 2018). Like unwanted tobacco smoke, noise doesn’t just bother people but also adversely affects human health and function. Secondhand smoke causes cancer, sudden infant death syndrome, respiratory disease in children, and coronary heart disease (Centers for Disease Control and Prevention [CDC], 2018). Similarly, unwanted single exposures to loud noise can cause hearing loss, tinnitus, and hyperacusis, whereas chronic noise exposure undoubtedly causes hearing loss and tinnitus. Noise disturbs concentration and interferes with learning. Chronic noise exposure has little known...

### Noise Mitigation Measures (road traffic)

![Diagram showing the distribution of noise mitigation measures for road traffic.]

- **Source Orientated Measures**
  - Road Traffic Management: 8%
- **Measures on the Propagation Path**
  - Measures at the receiver: 13%
- **Socio-economic Measures + Promotion & Awareness**
  - 25%

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**Tools to reduce the exposure of human to noise**
Motivation of Mitigating Noise in Urban context

Some noise is diffracted over the barrier.

Some noise is absorbed but low frequencies penetrate the barrier.
Our Proposed approach

- Urban high rise scenario → noise control at the receivers’ end
  - Point of entry into room interior → windows

- Active control strategy → performs well in low frequency range
  - Traffic noise falls within the effective range (< 2000 Hz)

- Practicality for domestic applications → retains most of the window’s functions
  - Greater inflow of natural ventilation compared to passive approaches → tropical climate
Outline of Talks

**Why Active Noise Control (ANC)?**
How it differs from passive noise control?

**How Active Noise Control Techniques can be extended from Headphones to Open Window?**

**What are some of the R&D results from NTU?**
Our latest published results
Key performance indicators for noise control
Why (Digital) Active Noise Control?

Digitisation of Noise Signal and apply Digital Techniques to Generate Anti-noise to Cancel out Incoming Noise and Achieve an Effective Noise Control Solution.
Active vs Passive Control Technology

Credit: ISVR (S. J. Elliott, 2015)
Principles of Active Noise Control (ANC)

To create *Destructive Interference*

Physics: Superposition

Noise: Primary source, $x$

Anti-Noise: Secondary source, $-x$

Math: $x + (-x) = 0$

\[
\text{Noise Reduction} = 10 \log_{10} \left[ 1 + \left( \Delta A \right)^2 + 2(\Delta A) \cos \phi \right] \text{ dB}
\]
Commercially Successful Products that use ANC Technology

ANC Headphones and Earbuds

Automobile with ANC

Pictures from internet
How to extend ANC headphones to ANC window?

Based on the same principle but extending across multiple secondary sources to cover a larger region of noise control at the window opening.
Three Domains of Single Channel ANC

- **Analogue-to-Digital domain**
  - Preamplifier
  - Anti-aliasing filter
  - ADC

- **Digital domain**
  - LMS

- **Acoustic domain**
  - Acoustic delay

Region of control only at the ear + Passive noise blocking earcup to handle the high frequency

Constraint of Causality

Acoustic Delay > Electronic Delay
Three Domains of $N$-Channel ANC for Open Aperture (Window)

- **Acoustic Domain**
  - Placement of sensors and actuator
  - Latency of A-D/D-A domain conversion

- **Analog-Digital Domain**
  - Fast, low cost, low power processor (controller), $(F_s = 25kHz, \text{ with hundred of taps FIR filter})$

- **Digital Processing Domain**
  - Multiplicity of units to handle multiple channels

**Contain noise at the window opening & result in global control for the entire room. No passive material.**
Active (noise control) strategies
The physical basis for active control

- Each active control problem has a unique set of optimisation problems
- Control source arrangement is the prime factor that determines the reduction of the noise reduction

ANC in Numerical 2D Simulation

Treating the noise at open windows leads to **global reduction** of noise levels in the whole room.

Optimal number of control sources w.r.t. to angle of incidence:

\[
N > \left[ \frac{L(1 + \sin\theta)}{\lambda} \right] \text{ for all } \theta \leq 90^\circ
\]


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**Urban Noise Webinar Series**

**School of Electrical & Electronic Engineering**

**Digitalisation of Urban Noise Sensing, Noise Control and Soundscape Technologies**

**Session 2**

**Active Noise Control and its Application for Mitigating Noise through Open Window**

**18 Aug 2020**

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![Diagram showing ANC in Numerical 2D Simulation](attachment: ANC_diagram.png)

500 Hz, 0 degree

1000 Hz, 0 degree

500 Hz, 30 degree

1000 Hz, 30 degree

**Treating the noise at open windows leads to global reduction of noise levels in the whole room.**
Real-time Active Control: Test chamber

Schematic of the mock-up room

Reference Microphone
Noise Source
Active Control Units
Window Grilles
Sliding Window

View of the active control system from the inside (L) and outside (R) of the mock-up chamber
Target: Achieve Noise Attenuation Globally Without Obstructing much Natural Ventilation and Light
What are some of the R&D results from NTU?

Report some of our latest published results and some key performance indicators for noise control.
Latest Results Published in the Nature Scientific Reports

A Proof-of-Principle Study


https://www.nature.com/articles/s41598-020-66563-z.pdf

Active control of broadband sound through the open aperture of a full-sized domestic window

Bhan Lam1, Dongyuan Shi2, Woon-Seng Gan1, Stephen J. Elliott1 & Masaharu Nishimura3

Shutting the window is usually the last resort in mitigating environmental noise, at the expense of natural ventilation. We describe an active sound control system fitted onto the opening of the domestic window that attenuates the incident sound, achieving a global reduction in the room interior while maintaining natural ventilation. The incident sound is actively attenuated by an array of control modules (a small loudspeaker) distributed optimally across the aperture. A single reference microphone provides advance information for the controller to compute the anti-noise signal input to the loudspeakers in real-time. A numerical analysis revealed that the maximum active attenuation potential outperforms the perfect acoustic insulation provided by a fully shut single-glazed window in ideal conditions. To determine the real-world performance of such an active control system, an experimental system is realized in the aperture of a full-sized window installed on a mockup room. Up to 10-dB reduction in energy-averaged sound pressure level was achieved by the active control system in the presence of a recorded real-world broadband noise. However, attenuation in the low-frequency range and its maximum power output is limited by the size of the loudspeakers.
Measurements in room of 2m x 2m x 2m

Microphone arrangement (ISO 16283-3:2016)
## Results

<table>
<thead>
<tr>
<th>Noise Type (Bandwidth, Hz)</th>
<th>Duration, s</th>
<th>Energy-average SPL, dBA</th>
<th>Planar-average SPL, dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before control</td>
<td>After control (Attenuation)</td>
</tr>
<tr>
<td>Gaussian white noise (100 to 1000)</td>
<td>10</td>
<td>74.60</td>
<td>65.80 (8.80)</td>
</tr>
<tr>
<td>Highway noise (100 to 1000)</td>
<td>6.64</td>
<td>72.93</td>
<td>64.26 (8.67)</td>
</tr>
<tr>
<td>MRT noise (100 to 1000)</td>
<td>12.64</td>
<td>77.47</td>
<td>67.33 (10.14)</td>
</tr>
<tr>
<td>Aircraft fly-by noise (100 to 1000)</td>
<td>19.11</td>
<td>70.69</td>
<td>63.18 (7.51)</td>
</tr>
</tbody>
</table>

**Table 1.** A-weighted energy-average sound pressure level of bandlimited urban transport noise recordings before and active control with windows fully opened, and without active control with windows fully closed. Values inside the parentheses indicate the attenuation level.
Figure 2. A-weighted energy-average spectrum of 100 Hz to 1 kHz band-limited (a) gaussian white noise, (b) highway noise, (c) MRT pass-by noise, and (d) aircraft fly-by noise, before active control ( ), after active control ( ), and with windows fully shut without active control ( ).
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(a) Energy-average: MRT 100 Hz to 1 kHz

(b) Energy-average: Aircraft 100 Hz to 1 kHz
Noise Reduction Performance (dB) using Acoustic camera

- Calibrated condenser microphone array
- Real-time noise source mapping (highest emitting source)
Bandlimited White Noise (400-1300Hz): ANC OFF
Bandlimited White Noise (400-1300Hz): ANC ON
Bandlimited MRT Noise (400-1200 Hz): **ANC OFF**
Bandlimited MRT Noise (400-1200Hz): ANC ON
Local/International Press Release

Window that silences your noisy neighbours ??

By Colin Fernandez
Science Correspondent

A WINDOW that can reduce noise pollution by 50 per cent even when open has been invented. The prototype is similar to basement window grilles, using a fibreglass mesh that is bonded to a frame. The mesh forms a pattern of interconnecting micro-cavities that act like sound-absorbing materials. When sound waves hit the mesh, some of the energy is absorbed by the micro-cavities, reducing the noise level at the window.

The invention was developed by researchers at Nanyang Technological University (NTU) in Singapore, where they have been working on sound-absorbing materials for several years. The team has been testing different designs and materials, and the prototype window has shown promising results.

"The objective is to develop a window that can be used in urban environments," said Professor Woon Seng Gan, the NTU professor who led the project. "The window should be effective at reducing noise without compromising the view or aesthetics of the building.

The window consists of a frame made from lightweight material, such as aluminium or plastic, and a mesh made from a special fibre that absorbs sound waves. The mesh is designed to fit into the window frame, and can be adjusted to fit different window sizes.

The window has already been tested in a prototype building, and the results have shown that it can reduce noise pollution by up to 50 per cent. The team is now working on improving the design and testing the window in real-world conditions.

Researchers believe that the window could be used in cities around the world, where noise pollution is a major concern. The invention could help to reduce the noise levels in crowded urban areas, improving the quality of life for residents.

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Limitations & Conclusions

Key Takeaways of this Talk
Limitations of ANC Window Techniques

• Limited to low frequency noise control less than 1500 Hz.
• Absence of ANC below 300 Hz is primarily due to the implementation of small loudspeakers (to reduce visual obstruction and minimize blocking natural ventilation)
• Need to distribute secondary sources around the window opening; and at the same time, allow natural ventilation
• Requires high-speed processors and low latency electro-acoustic elements
• However, ANC is not a silver bullet for controlling every types of noise!
Conclusions

• Demonstrated and reported a proof-of-principle study in Nature Scientific Report.

• Successful in reducing the volume of noise transmitted through an open window.

• Reduction of up to 10 dB has been achieved in space and time averaged sound pressure levels.

• With the advent of powerful processing units, low cost sensors and actuators, and advanced signal processing and AI techniques, digital ANC technique is becoming a viable tool to reduce urban noise.
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