Personal active soundfield control (using wearable audio devices)

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Emerging new mode of audio devices: “wearable loudspeakers”

- Unique mode of audio presentation which is open and personal at the same time (which can be a dilemma)
- What can we do with this new unique device?

* From SONY web site

* From BOSE web site
Sound control in open space

- Active sound control is expanding from closed spaces (ANC headphones / earphones) to loudspeaker arrays in open space


- Crosstalk cancellation (XTC; transaural audio playback)

Personal active soundfield control

• Using wearable open audio devices (loudspeaker / microphone arrays) to actively control personal sound fields.

• Control targets:
  • Outgoing fields:
    • Speech privacy
  • Incoming fields:
    • Personal active noise control
  • Local fields:
    • Immersive AR audio presentation

\[
p^{(\text{tot})} = p^{(\text{rad})} + p^{(\text{ex})} + p^{(\text{can})} + p^{(\text{tra})}
\]

Total field

Radiation field

External field

Cancellation field (anti-noise)

Transaural field
Formulation: costs and solutions

• Task 1: Active radiation cancellation (ARC)

\[ L^{(\text{ARC})}_\lambda = \| P^{(\text{rad})}_{\text{test}} + H_{\text{ts}} c^{(\text{can})} \|_2^2 + \lambda \| c^{(\text{can})} \|_2^2 \rightarrow c^{(\text{can})}_{\text{opt}} = - (H_{\text{ts}}^H H_{\text{ts}} + \lambda I)^{-1} H_{\text{ts}}^H P^{(\text{rad})}_{\text{test}} \]

• Task 2: Personal open ANC

\[ L^{(\text{ANC})}_\lambda = \| P^{(\text{res})}_{\text{probe}} \|_2^2 + \lambda \| c^{(\text{can})} \|_2^2 \rightarrow c^{(\text{can})}_{\text{opt}} = - (H_{\text{ms}}^H H_{\text{ms}} + \lambda I)^{-1} H_{\text{ms}}^H P^{(\text{ext})}_{\text{probe}} \]

• Task 3: XTC

\[ L^{(\text{XTC})}_\lambda = \| s^{(\text{bin})} - H_{\text{rtf}} H_{\text{xtc}} s^{(\text{bin})} \|_2^2 + \lambda \| H_{\text{xtc}} s^{(\text{bin})} \|_2^2 \rightarrow H_{\text{xtc}} = (H_{\text{rtf}}^H H_{\text{rtf}} + \lambda I)^{-1} H_{\text{rtf}}^H \]
Global cost function for hyperparameter optimization

- Global cost function (for task 1):

\[ L^{(\text{glob})}(\lambda) = -R(p_{\text{opt}}) \]

\[ R(p_Q) = 20(\log_{10}\|p_Q^{(\text{rad})}\|_2 - \log_{10}\|p_Q^{(\text{res})}\|_2) \]

... reduction level on “optimization points” Q, a set of points which is distinct from the test (control) points.

- Hyper parameter \( \lambda \) is optimized by grid search to minimize the global cost function.

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FEARLESS IDEAS
Numerical experiment

- **Geometry:**
  - A humanoid in front of a desk with a laptop screen on top
  - Loudspeakers:
    - neckband loudspeaker array or loudspeaker array installed in laptop (2ch or 7ch)

- **Transfer function computation:**
  - Fast-multipole BEM
Results: task 1 - speech privacy

- Point source in the vicinity of the mouth
- Test & optimization points: 2048 points (spherical Fibonacci grid) at distance 0.5m and 0.7m, respectively.
- Reduction observed at low frequencies (< 1 kHz)

Simulation using measured IRs and human speech as input
Results: task 2 - personal open ANC

- Similar reduction observed at low frequencies (< 1 kHz) for both worn and frontal loudspeakers
- Spatial characteristics are very different

Reduction in the vicinity of the ears

Significant noise injection into the space
Results: task 2 - personal open ANC

• While the reduction level was similar, worn loudspeakers required significantly less energy.
Conclusion

- Two personal active sound control tasks (personal ANC & ARC) using a wearable loudspeaker array have been studied by means of numerical simulation.
- Successful control was observed at low frequencies (< 1kHz)
- Wearable loudspeakers were found to achieve personal ANC with less energy compared to frontal loudspeaker arrays
  - This can be understood as a result of the proximity of the loudspeakers and the head/neck being natural acoustic obstacles reducing crosstalk → good indication for reducing the noise injection side-effect and for the XTC task
  - Wearable loudspeakers seem to solve the “personal-while-open” objective better
- Future research:
  - Developing signal processing which considers nonlinearities of the small loudspeakers in wearable devices
  - Content-dependent smart control of radiated/incident/local sounds using statistical learning from data
Thank you very much for your attention!
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