Spatio-Temporal Sampling and Distributed Compression of the Sound Field

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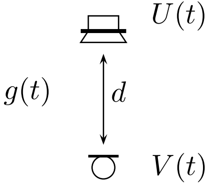
EUSIPCO, Florence, Italy - September 5, 2006

Outline

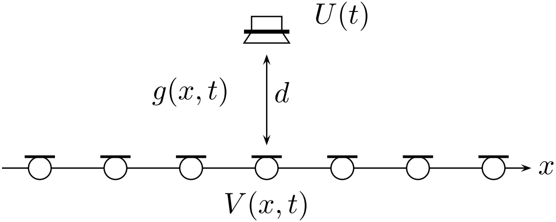
1. Problem Statement
   - Recording Setups
   - Properties of the Sound Field
   - Measurements
2. Spatio-Temporal Sampling
   - Generalities
   - Sampling Lattices
3. Distributed Compression
   - Generalities
   - Linear Array Setup
   - Hearing Aids Setup
4. Conclusions

Problem Statement: Recording Setups

- At a given position:

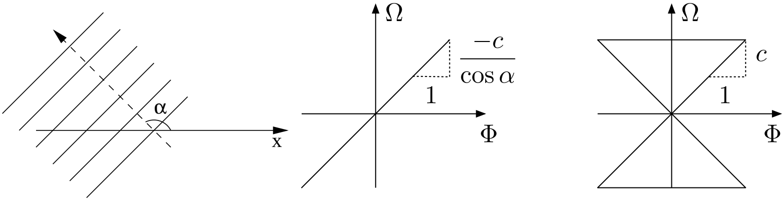


- Along a line:



Problem Statement: Far-Field Case

- Sources are modelled as plane waves [Figure (a)]
- When a plane wave arrives on a line of microphones, the 2D spectral support is a line [Figure (b)]
- When plane waves arrive from every possible angle, the 2D spectral support is a bow-tie [Figure (c)]

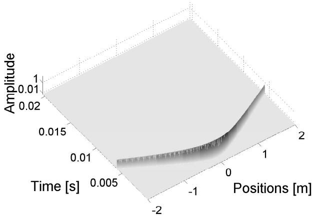


(a) (b) (c)

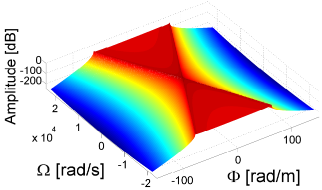
Problem Statement: Near-Field Case

- Sources are no longer modelled as plane waves [Figure (a)]
- A near-field source is recorded along a line, the amplitude of its 2D spectrum is computed [Figure (b)]
- Most of the energy is in the 2D spectral region given by:

$$|\Phi| \leq \frac{|\Omega|}{c}$$



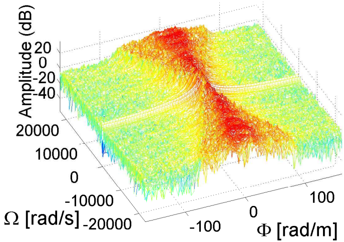
(a)



(b)

Problem Statement: Measurements

- 71 room impulse responses measured along a line in a room (2 cm spacing)
- Similar spectrum observed:



Spatio-Temporal Sampling: Generalities

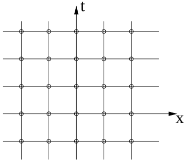
- From continuous space-time fields to samples:

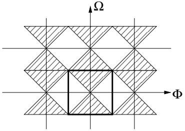
$$V(x,t) \longrightarrow V[n,k] = V(x_n, t_k)$$

- A microphone array acts as a spatio-temporal sampling device for the sound field
- Goal: to faithfully represent the sound field $V(x,t)$ with the samples $V[n,k]$

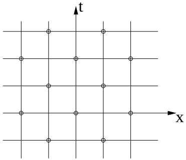
Spatio-Temporal Sampling: Sampling Lattices

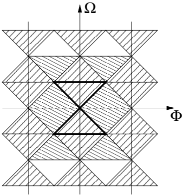
- Rectangular sampling lattice:





- Quincunx sampling lattice:





Distributed Compression: Generalities

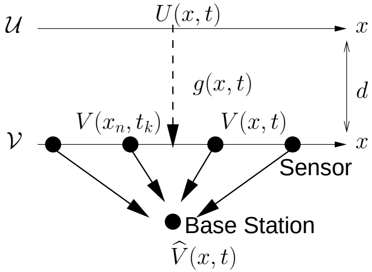
- From samples to bits:

$$V[n, k] \longrightarrow 001001010010011110$$

- The sensors transmit these bits over parallel rate-constrained channels to a base station which reconstructs the original sound field $V(x, t)$ as $\hat{V}(x, t)$
- Goal: to minimize the total bit rate R used by the sensors for a given average distortion D

Distributed Compression: Linear Array Setup

- Linear array setup:



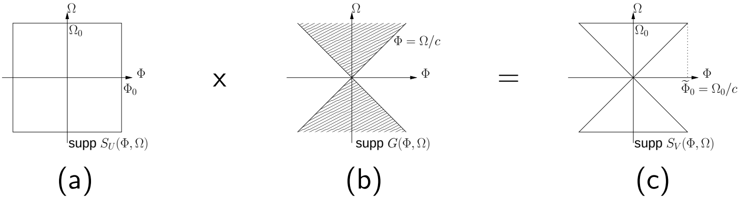
Distributed Compression: Linear Array Setup (cont'd)

- Source coding schemes:

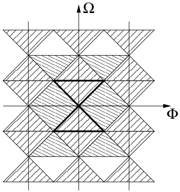
	inter-sensor communications	correlation taken into account	processing complexity
centralized	free	spatio-temporal	unbounded
spatially independent	none	temporal	unbounded
multiterminal	none	spatio-temporal	unbounded

Distributed Compression: Linear Array Setup (cont'd)

- Assumptions: far-field case, Gaussian processes, flat PSDs
- The 2D spectral support of (a) the source $U(x,t)$, (b) the filter $g(x,t)$ and (c) the observation $V(x,t)$

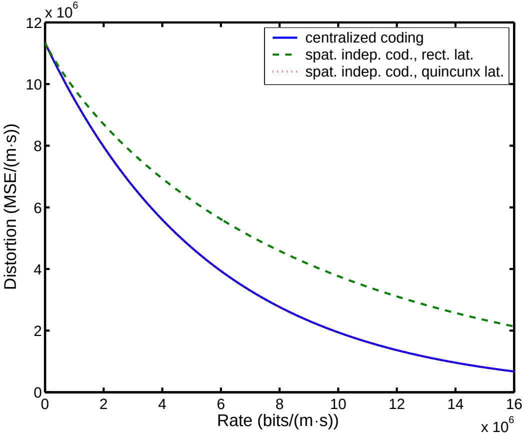


- Appropriate quincunx sampling grid:



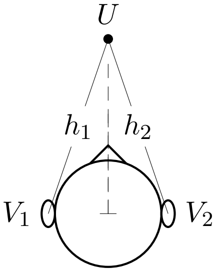
Distributed Compression: Linear Array Setup (cont'd)

- Rate-distortion functions:

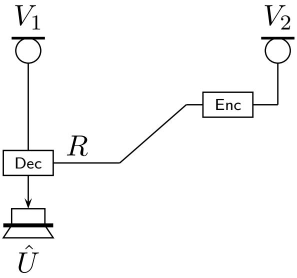


Distributed Compression: Hearing Aids Setup

- Hearing aids setup:
  (a) Typical head-related configuration
  (b) Collaboration using a wireless communication link



(a)



(b)

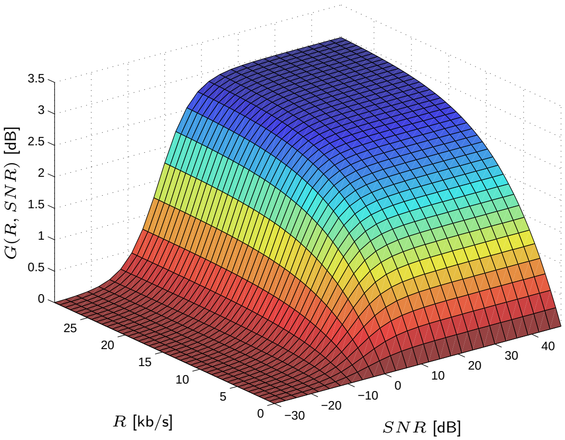
Distributed Compression: Hearing Aids Setup (cont'd)

- Assumptions: far-field case, Gaussian processes, flat PSDs, source and ambient noise
- Remote source coding problem with side information
- We define the gain-rate function as:

$$G(R) := \frac{D(0)}{D(R)}$$

Distributed Compression: Hearing Aids Setup (cont'd)

- Gain-rate function:



Conclusions

- Spatio-temporal characteristics of the sound field
- Sampling results for different sampling lattices
- Distributed compression:
  - Linear array setup: optimal rate-distortion tradeoff by judicious (and simple) signal processing at the sensors
  - Hearing aids setup: optimal gain-rate tradeoff for collaborative beamforming

Conclusions

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- Distributed compression:
  - Linear array setup: optimal rate-distortion tradeoff by judicious (and simple) signal processing at the sensors
  - Hearing aids setup: optimal gain-rate tradeoff for collaborative beamforming

Take-home message:
tailor your communication scheme to physical™ reality

References

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- R. L. Konsbruck, E. Telatar, and M. Vetterli, “On the multiterminal rate-distortion function for acoustic sensing,” *IEEE International Conference on Acoustics, Speech, and Signal Processing*, vol. 4, pp. 701–704, May 2006.
- O. Roy and M. Vetterli, “Rate-constrained beamforming for collaborating hearing aids,” *IEEE International Symposium on Information Theory*, pp. 2809–2813, July 2006.