ACOUSTIC SOURCE SEPARATION VIA PARTICLE VELOCITY VECTOR MEASUREMENT

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1. Introduction

   Background
   Independent Component Analysis
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2. Problem Formulation

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Acoustic Blind Source Separation — Background —

Percussion instrument

Trumpet | Toronbone | Tuba

Horn

Clarinet | Fagotto

Flute | Oboe

2nd Violin

Cello

1st Violin

Viola

The conductor’s ears can discriminate:

- Sound Pressure from each instrument
- DOA of each instrument
The stereo microphones

- can record only the mixture of Sound Pressure from all instruments
- cannot discriminate DOA of each instrument
The objective of BSS-microphone system to discriminate:

- Sound Pressure from each instrument
- DOA of each instrument
Independent Component Analysis – key of Acoustic BSS —

- Percussion instrument:
  - Trumpet
  - Toronbone
  - Tuba

- Wind instruments:
  - Horn
    - Clarinet
    - Fagotto
    - Flute
    - Oboe

- Strings instruments:
  - Harp
  - 2nd Violin
  - Cello
  - 1st Violin

- Other instruments:
  - Viora

Acoustic BSS ⇒ Convolutive BSS:
- Frequency Domain ICA ← popular
- Time Domain ICA

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Frequency Domain Independent Component Analysis

\[ W(\eta) \]

\[ f_1(t) \]
\[ f_2(t) \]

\[ g_1(t) \]
\[ g_2(t) \]

Short-time FFT

Optimize \( A(\eta) \) for each frequency bin

Frequency bin

\[
\begin{pmatrix}
\hat{W}_1(\eta_1) & \hat{W}_2(\eta_1) \\
\hat{W}_2(\eta_2) & \hat{W}_1(\eta_2) \\
\hat{W}_1(\eta_3) & \hat{W}_2(\eta_3) \\
\vdots & \vdots \\
\hat{W}_1(\eta_m) & \hat{W}_2(\eta_m)
\end{pmatrix}
\]

\[ \hat{w}_1(t) \]
\[ \hat{w}_2(t) \]

Difficulties in FDICA:
- Permutation in frequency bin
- Missing DOA
Spatio-Temporal Gradient Domain ICA

\[ \Delta g_1(t) \]
\[ \Delta g_2(t) \]
\[ \int dt \]
\[ \int dt \]

\[ A(t) \]

\[ v(t) \]

\[ \hat{w}_1(t) \]
\[ \hat{w}_2(t) \]

Optimize \[ A(t) \]

vector sensor

particle velocity vector
Objectives

- The spatio-temporal blind signal separation algorithm utilizes the linearity among the four signals:
  1. the sound pressure,
  2. x-directional particle velocities,
  3. y-directional particle velocities,
  4. z-directional particle velocities,
  all of which are governed by the equation of motion in order to make the convolutive blind source separation problems into the simplest instantaneous mixture problems.
- The directions of wave propagations can be determined with the proposed blind source separation.

- application
  - tele-meeting system
  - mobile phone
  - hearing aid
1. Introduction

2. Problem Formulation
   Instantaneous linear mixture
   Blind Source Separation

3. Acoustical Experiments

4. Concluding Remarks
**Instantaneous linear mixture**

- Base on the wave equation of the airborne sound:

\[ \nabla f(x, y, z, t) \big|_{x=y=z=0} = A \begin{pmatrix} \dot{w}_1(t) \\ \dot{w}_2(t) \\ \dot{w}_3(t) \end{pmatrix}, \quad (1) \]

- From the equation of motion particle velocity vector \( \mathbf{v}(x, y, z, t) \) and the spatial gradients of the sound pressure \( f(x, y, z, t) \) satisfy:

\[ \rho \frac{\partial \mathbf{v}(x, y, z, t)}{\partial t} = -\nabla f(x, y, z, t), \quad (2) \]

where \( \rho \) is the density of the air.

- The instantaneous linear mixture can be denoted as:

\[ \rho \frac{\partial \mathbf{v}(x, y, z, t)}{\partial t} \big|_{x=y=z=0} = -A \begin{pmatrix} \dot{w}_1(t) \\ \dot{w}_2(t) \\ \dot{w}_3(t) \end{pmatrix}. \quad (3) \]
Microphone which detects the particle velocity can make the convolutive cocktail-party problems into the simplest instantaneous linear mixture problems.
**Instantaneous linear mixture**

\[ \rho \frac{\partial \mathbf{v}(x, y, z, t)}{\partial t} \bigg|_{x=y=z=0} = -A \begin{pmatrix} \dot{w}_1(t) \\ \dot{w}_2(t) \\ \dot{w}_3(t) \end{pmatrix}. \]  

(7)

\[ \int dt \rho \frac{\partial \mathbf{v}(x, y, z, t)}{\partial t} \bigg|_{x=y=z=0} = - \int dt A \begin{pmatrix} \dot{w}_1(t) \\ \dot{w}_2(t) \\ \dot{w}_3(t) \end{pmatrix}. \]  

(8)

\[ \rho \mathbf{v}(x, y, z, t) \bigg|_{x=y=z=0} = -A \begin{pmatrix} w_1(t) \\ w_2(t) \\ w_3(t) \end{pmatrix}. \]  

(9)

\[ \mu \text{icroFlown which detects the particle velocity can make the convolutive cocktail-party problems into the simplest instantaneous linear mixture problems.} \]
1. Pre-whitening
2. Iterative Blind source separation via rotation process
3. DOA estimation
3. Acoustical Experiments

1. Introduction

2. Problem Formulation

3. Acoustical Experiments
   \( \mu \)icro \( f \)lown
   Proof of Concept Model
   Source Signals
   Separated Signals

5. Concluding Remarks
μicro flown
Proof-of-Concept model

(1) Proof-of-Concept model

(2) Diagram showing the setup with the following details:
- left speaker
- right speaker
- 0.5m distance from the center
- \( \phi_1 = \frac{2\pi}{3} \) (rad)
- \( \phi_2 = \frac{\pi}{3} \) (rad)
- 3-ch Microflown
- Digital Storage Oscilloscope
- signal conditioner
- PC
- GP-IB

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### Source Signals, Observed Signal

<table>
<thead>
<tr>
<th></th>
<th>No.1</th>
<th>No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>source</td>
<td>female voice, ENGLISH</td>
<td>female voice, JAPANESE</td>
</tr>
<tr>
<td>length</td>
<td>20s</td>
<td>20s</td>
</tr>
<tr>
<td>arrival directions</td>
<td>$\theta_1 = 0 \text{ (rad)}$ $\phi_1 = 2\pi/3 \text{ (rad)}$</td>
<td>$\theta_2 = 0 \text{ (rad)}$ $\phi_2 = \pi/3 \text{ (rad)}$</td>
</tr>
</tbody>
</table>

1. ![Graph 1](test15-10.dat)
2. ![Graph 2](test15-20.dat)
3. ![Graph 3](test15x0.dat)
4. ![Graph 4](test15y0.dat)
Separated Signals

![Separated Signals Graphs](image-url)

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DOA and SIR

(1)

\[ \phi_2 = \frac{2\pi}{3} \]
\[ \phi_1 = \frac{\pi}{3} \]

(2)

SIR(dB)

SIR1

SIR2
Discussion and Remarks

1. The spatio-temporal gradient analysis has an ability to simplify the convolutive blind source separation problems into the instantaneous blind source separation over the spatio-temporal gradient space,

2. The directions of wave propagations can be determined with the proposed blind source separation.

3. Three sources can be discriminated autonomously even when they are slightly moving.