Presentation at the
Workshop em Acústica Submarina 2000
Rio de Janeiro, 8-11 November 2000

by

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Optimal and sub-optimal matched field correlators

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This work was supported under contract 2./2.1/MAR/1698/95, PRAXIS, FCT, Portugal
Issues

- source localization
- ocean acoustic tomography
- geoacoustic inversion
- underwater communications
Ocean Acoustic Tomography - synoptic

acoustic pressure

receiver

source

source signal

Correlator

Optimization

Acoustic Model

new environment

\[ s(t) \text{ (source signal)} \]

\[ y \]

\[ r(\zeta) \]

\[ p(\zeta) \]

\[ \hat{\zeta} \]
Source localization (MFP) - synoptic

Acoustic Model

Correlator

Ambiguity surface

Acoustic pressure

receiver

source

environment

\( p(r,z) \)\n
\( b(r,z) \)
Problem: intersymbol interference due to the channel multipath

h(t) is a "guess" of the channel impulse response

Underwater Acoustic Communications
DATA INVERSION STRATEGY

Matched Filter

\[
C(\gamma) = \frac{1}{L} \sum_{i=1}^{L} y_i^* P_i(\gamma)
\]

Acoustic Propagation Model (SAFARI)

\[
P_i(\gamma); i = 1, \ldots, L
\]

Sensor data

\[y_i; i = 1, \ldots, L\]

Array position data

Environmental data (known)

Geoacoustic parameter (\(\gamma\))
Data-model and the problem

Data model:

\[ y(t, r) = x(t, r) + n(t) \]
\[ x(t, r) = g(t, r) \ast s(t) \]

Problem: find the filter \( h(t, r) \)

\[ z(t, r) = h(t, r) \ast y(t, r) \]
\[ = z_0(t, r) + n_0(t) \]

that maximizes the SNR \( \rho(t, r) \)

\[ \rho(t, r) = \frac{|z_0(t, r)|^2}{<n_0^2>} \]
Generalized Matched Filter

Signal-to-noise ratio (SNR): \[ \rho(t, r) = \frac{1}{2\pi} \left| \frac{\int_{\Omega} H(\omega, r) G(\omega, r) S(\omega) e^{j\omega t} d\omega}{\int_{\Omega} |H(\omega, r)|^2 P_{nn}(\omega) d\omega} \right|^2 \]

Minimized by: \[ H(\omega, r) = H_0 \frac{G^*(\omega, r) S^*(\omega, r)}{P_{nn}(\omega)} e^{-j\omega \tau} \]

Max SNR: \[ \rho_{\text{max}}(r) = \frac{1}{2\pi} \int_{\Omega} \frac{|G(\omega, r)|^2 |S(\omega)|^2}{P_{nn}(\omega)} d\omega \]
Performance of the GMF

Considering white-noise, i.e., \( P_{nn}(\omega) = \frac{N_0}{2} I \),

\[
\rho(t, r) = \rho_{\text{max}}(r) |\Lambda(t, r)|^2
\]

with

\[
\Lambda(t, r) = \frac{\int_{\Omega} \hat{G}^*(\omega, r) G(\omega, r) |S(\omega)|^2 e^{j\omega(t-r)} d\omega}{\left[\int_{\Omega} |\hat{G}(\omega, r)|^2 |S(\omega)|^2 d\omega \right]^{1/2} \left[\int_{\Omega} |G(\omega, r)|^2 |S(\omega)|^2 d\omega \right]^{1/2}}
\]

\[
\rho_{\text{max}}(r) = \frac{2\epsilon_x}{N_0}
\]
GMF vs. MF

Known channel response: \( \hat{G}(\omega, \mathbf{r}) = G(\omega, \mathbf{r}) \)

\[
\rho_{\text{GMF}}(\mathbf{r}) = \rho_{\text{max}}(\mathbf{r})
\]

Unknown channel response: \( \hat{G}(\omega, \mathbf{r}) = 1 \)

\[
\rho_{\text{MF}}(\mathbf{r}) = \rho_{\text{max}}(\mathbf{r}) \alpha(\mathbf{r})
\]

\[
\alpha(\mathbf{r}) = \frac{\max_{t} \int_{\Omega} |G^*(\omega, \mathbf{r})| S(\omega)|^2 e^{j\omega(t-\tau)} d\omega|^2}{\int_{\Omega} |S(\omega)|^2 d\omega \int_{\Omega} |G(\omega, \mathbf{r})|^2 |S(\omega)|^2 d\omega}.
\]
Gain of including environmental information is

\[ \text{Gain} = \frac{\rho_{\text{GMF}}(r)}{\rho_{\text{MF}}(r)} = \frac{\max_t |\Lambda(t, r)|^2}{\alpha(r)}. \]

\[ \max_t |\Lambda(t, r)|^2 \leq 1 \]

\[ \alpha(r) \leq 1 \]

\[ \Rightarrow \text{Gain can be } < 1! \]
Simulations

- range independent case: 135 m water depth, INTIMATE’96
- normal-mode model SNAP
- \( f \in [50, 150] \) Hz
Conclusions

- generalized matched-filtering (GMF) can be very rewarding:
  - increase parameter space
  - estimation/detection capabilities
- simple matched-filtering (MF) can have higher SNR output than GMF depending on signal time spread and environmental characteristics mismatch
- tests for optimality to be performed for each case
INTIFANTE’00 Sea Trial
Setúbal, 9-29/Oct/2000

Objectives

- INFANTE’00
  1. underwater communications (UWA modem)
  2. surface autonomous vehicle navigation (DELFIM)
  3. environmental effects in underwater communications (vTRM)
- INTIMATE’00
  1. acoustic observations of internal tide effects
  2. single sensor source localization in highly variable environments
  3. acoustic tracking of non-linear effects (solitary waves)
  4. passive tomography (TOMPACO - ship noise)

Ressources

- 4 institutions (IH, IST, CINTAL/UALg, ENEA)
- two vertical arrays (LF 16-hyd, HF 4-hyd)
- CTD’s, currentmeters, bathymetry, sidescan sonar, seismic (Uniboom), HF (50 Khz) underwater acoustic modems, DGPS, LF acoustic source (NATO-SACLANTCEN), SST, SAR, thermistor chains, XBT’s, etc...
Real Data Acquisition Scenario
INTIMATE'00, OUT 2000 - SW Setúbal site

Setúbal

38°30'

38°15'

8°45'

9°00'

~110 m

~500 m

Sediment

Setúbal Canyon

UltraLight Vertical Array (ULVA)

SoundSource

NRDOm Carlos
## Event list

<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>INFANTE’00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>underwater acoustic modem directivity (50 kHz)</td>
<td>N</td>
</tr>
<tr>
<td>II</td>
<td>bottom module - HFA communication (50 kHz)</td>
<td>N</td>
</tr>
<tr>
<td>III</td>
<td>surface module - HFA communication (20 kHz)</td>
<td>Y</td>
</tr>
<tr>
<td>IV</td>
<td>DELFIM catamaran navigation for AUV data communication</td>
<td>Y</td>
</tr>
<tr>
<td>INTIMATE’00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>PSK, FSK, probe (1.8 kHz) virtual time-reversal mirror</td>
<td>Y</td>
</tr>
<tr>
<td>II</td>
<td>LFM (170-600 Hz) range-independent transmissions - internal tide</td>
<td>Y</td>
</tr>
<tr>
<td>III</td>
<td>LFM (170-600 Hz) range-dependent transmissions - localization</td>
<td>Y</td>
</tr>
<tr>
<td>IV</td>
<td>LFM (170-600 Hz) across-canyon transmissions - localization</td>
<td>Y</td>
</tr>
<tr>
<td>V</td>
<td>BB noise transmissions for passive tomography</td>
<td>Y</td>
</tr>
<tr>
<td>VI</td>
<td>Ship noise transmissions for passive tomography</td>
<td>Y</td>
</tr>
</tbody>
</table>
Event 2: LFM – A3, 16Oct00 – 13:54:00 UTC
Event6: Ship noise, 18Oct00 – 02:26:30 UTC

Event6: PSD 0−30 sec, 18Oct00 – 02:26:30 UTC

Event6: PSD 30–100 sec, 18Oct00 – 02:26:30 UTC