BROADBAND SYNTHETIC APERTURE MATCHED FIELD GEOACOUSTIC INVERSION WITH A SINGLE HYDROPHONE

Bien Aik Tan, Peter Gerstoft, Caglar Yardim, and William Hodgkiss

- Single source and receiver method for low SNR
- Long observation time of P LFM chirps
- Requires waveguide Doppler

http://www.mbari.org/auv/
MOTIVATION

- Single source/receiver method – operationally attractive.
- To exploit frequency diversity, we use frequency-coherent MFP.
- For SNR gain, we coherently exploit multiple LFM's. But method becomes Doppler intolerant.
- To rectify, waveguide Doppler and a different frequency sampling is used.
- Some applications
  - Low SNR scenarios.
  - Source level restrictions (e.g. marine wildlife, expendable sources).
  - Rapid environment assessment with AUVs.

Motivation

Theory

Simulation

Experimental Data

http://www.mbari.org/auv/
COHERENTLY EXPLOITING MULTIPLE LFMS

- P LFMs
- 100–900 Hz $T=1$ s $T_r=1$ s
- Periodic peaks at $1/T_r$ Hz

**Motivation**

- Peak samplings and doubling P
  - Signal peak increases 6 dB
  - Noise level increase 3dB
  - SNR gain is 3dB
  - Increasingly Doppler intolerant

**Mathematical Formulation**

\[ S_c(f) = \sum_{p=0}^{P-1} \exp(i2\pi fpT_r)S(f) \]

\[ \{S(t) \ast \sum \delta(t - nT_r)\} \ast \text{rect}\left\{\frac{t - PT_r/2}{PT_r}\right\} \]

\[ \{S(f) \times \sum \delta(f - j/T_r)\} \ast PT_r \cdot \text{sinc}\{f PT_r\} \]
WAVEGUIDE DOPPLER

- 1994 Schmidt and Kuperman
  - Spectral/Modal Solution
  - Non-reciprocity
  - Frequency domain

- Each mode has a different Doppler

Example: 400 Hz harmonic source (KRAKEN)

\[
\omega_s^{(k_n)} = \frac{\omega_r - k_n(v_s - v_r)}{\omega_s} \\
\omega_r = \omega_s + k_n v_s \\
\omega_r^{(k_n)} = \omega_s + k_n(v_s - v_r)
\]

Motivation  Theory  Simulation  Experimental Data
SW06 SIMULATION

LFM 100–900 Hz $T=1$ s $T_r=1$ s

- Static source/receiver
  - Coherently exploit P LFM
- Moving source & static receiver
  - Waveguide Doppler
  - Enhanced frequency sampling

\[
\{\xi, x\}_{ML} = \arg\max_{\xi, x} \left[ \ln L(\xi, x) \right]
\]
\[
= \arg\min_{\xi, x} \left[ 10 \log_{10} \Phi(\xi, x) \right]
\]

where the cost function
\[
\Phi(\xi, x) = 1 - \frac{|y^H \tilde{C}_w^{-1} b|^2}{y^H \tilde{C}_w^{-1} y b^H \tilde{C}_w^{-1} b}
\]
STATIC SOURCE / RECEIVER

Motivation

Theory

Simulation

Experimental Data

Monte Carlo inversion versus $P=\{1, 2, 4, 8, 16, 32, 64\}$

- 200 noise realizations
- SNR = $-6$ dB
- Peak frequency sampling $\Delta f = 5$ Hz
Moving Source & Static Receiver

Source radial speed is 2.5 m/s

- Propagate
- For high P values, peak sampling = loss of higher modes
- Waveguide Doppler
- Peak ± Doppler spread Hz sampling
SW06 EXPERIMENT

- JD238 2029 UTC
- Source: J-15, 30 m, LFM 100–900 Hz $T=1$ s $T_r=1$ s, 2.5 m/s
- Receiver: Hydrophone 8 of VLA, 44.6 m
- Source – receiver range ~2050–2100 m
- SNR ~ −6 dB

SHARK interpolated sound speed profile

Motivation  Theory  Simulation  Experimental Data
INVERSION RESULTS

SW06 data inversion results $p=64$ using waveguide Doppler

- Motivation
- Theory
- Simulation
- Experimental Data
INVERSION RESULTS

SW06 data inversion results $P=64$

- Uniform and waveguide Doppler use same peak and span freq. sampling
- Uniform Doppler
  - Applied free space Doppler prior to waveguide propagation
  - Sediment velocity profile estimate adversely affected
  - Relatively lower sensitivities = higher estimation uncertainties

- Waveguide Doppler

Motivation  Theory  Simulation  Experimental Data
CONCLUSION, QUESTIONS & ANSWERS

Thank you!

- Single hydrophone broadband matched field inversion in low SNR.
- Coherently exploits multiple LFM s to increase SNR.
- Waveguide Doppler and increased frequency sampling is needed.