Research activities in underwater acoustics at NTNU

Hefeng Dong
Department of Electronics and Telecommunications
Acoustics

NAS meeting Trondheim, 23-24.10. 2015
Underwater Acoustics

Study sound propagation in water column and sea bottom, and interaction with sea surface and sea bottom for

- Detection and localization of target and object in underwater or buried in the seabed
- Seabed characterization
- Underwater acoustic communication
- Underwater positioning and navigation
Underwater Acoustics Research

- **Acoustic Remote Sensing**
  - Numerical modeling of sound propagation in fluid, elastic and pore elastic media
  - Seabed characterization by model-based geoacoustic inversion
  - Passive acoustics: ocean ambient noise, ship & seismic noise

- **Underwater Acoustic Communication**
  - Algorithm and acoustic modem design for effective and reliable acoustic communication
  - Channel modeling, optimal sensor node positioning and reliable wireless communication between sensor nodes
  - Instrumentation and underwater acoustic experiments
Acoustic Remote Sensing for seabed properties

- **Shear wave velocity in the sediments**
  - Interface waves and ocean ambient noise by horizontal array on/close to the seafloor

- **Seismic velocities in the basalt**
  - Reflection data by towed horizontal array in the water column

- **P-wave velocity & attenuation in the sediment**
  - Pressure data by vertical hydrophone array in the water column
Inversion methods

- **Linearized inversion**
  - Singular value decomposition

- **Nonlinear inversion**
  - Optimization
    - ASSA (adaptive simplex simulated annealing)
    - DE (differential evolution)
    - GA (genetic algorithms)
  - Bayesian approach
Bayesian Inversion

- Bayes’ rule: \( P(m|d)P(d) = P(d|m)P(m) \)
- MAP (maximum a posteriori) values
- Marginal probability distribution
- Uncertainty
- Optimal parameterization: \( \text{BIC} = 2E(\hat{m}) + M \log_e N \)
Ocean ambient noise recording

- 196 fiber-optical sensors with 50m spacing
- 2.38 hours recording
- Water depth of 316m – 343m
Multi-component noise data
Data processing

- Low-pass filtering (0.68-6 Hz)
- One-bit normalization
- Segmentation (4.5s each segment)
- Cross-correlation and stacking (1720 segments)
- Gathers (30 Green’s functions each gather)
Green functions - pressure
Phase-velocity dispersion
Inversion results
Marginal probability profile
Underwater Acoustic Communication

Limitations on underwater communication channel:

- Time-varying
- High dispersive
- Extended multipath
- Bandwidth limited
- Complex bathymetry
- Ambient noise
Channel measurements

Impulse response 202.044 s/frame
Development of real-time single carrier frequency domain Turbo Equalizer

- Low computational complexity
- Suitable for quasi-static channel
- Overall data rate 4 ks/s
Development of underwater OFDM acoustic communication system

- Time-domain oversampled technique to explore potential Doppler and delay diversity
- Iterative ICI equalizer and channel estimation to further improve performance
- OMP sparse channel estimator to explore channel inherent sparsity
- Real-time system implemented on Multi-core DSP

**CPU processing time**

<table>
<thead>
<tr>
<th>Function</th>
<th>Processing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFO compensation</td>
<td>0.76 ms</td>
</tr>
<tr>
<td>Vector norm calculation</td>
<td>0.101 ms</td>
</tr>
<tr>
<td>OMP channel estimation</td>
<td>87.7 ms</td>
</tr>
<tr>
<td>ICI equalization &amp; Soft demapper</td>
<td>5.25 ms</td>
</tr>
<tr>
<td>SISO decoder</td>
<td>6.77 ms</td>
</tr>
<tr>
<td>Soft mapper</td>
<td>0.347 ms</td>
</tr>
<tr>
<td>Total time per iteration</td>
<td>101 ms</td>
</tr>
</tbody>
</table>
Channel modeling and optimization

- Underwater acoustic channel modeling for underwater network and vehicle navigation
- Optimization of channel condition for Long Base-Line localization (AUVs)
- Prediction of channel conditions for path planning of underwater vehicles (AUVs)
Underwater Acoustic Communication between nodes

- Underwater communication between different nodes in underwater networks
- Studying different algorithms to optimize the communication performance
- Sea experiments in Trondheim fjord for testing the algorithms
Acoustic Underwater Laboratory – (AUL)

- Low-high freq. transmitters (850Hz, 12kHz & 40 kHz)
- Power amplifier
- 3 broadband vertical hydrophone arrays (8-element for each)
- 32-channel filter
- 24-channel amplifier
- 32-channel data acquisition system
- Autonomous acquisition (stand-alone hydrophones in Spring 2016)
- NTNU research vessel – R/V Gunnerus
Instruments
Underwater Communication experiments in Trondheim fjord

Sea experiments performed in Trondheim fjord in the past 6 years with different configurations to test different algorithms for supporting the research and educational program.
Courses in Underwater Acoustics

- Marine Acoustics (Master)
- Acoustic Remote Sensing (Specialization)
- Marine Acoustics II (Specialization, PhD)
- Geoacoustic Modeling and Inversion (PhD)
Acknowledgement

Thanks PhD candidates
  ▪ Bo Peng
  ▪ Slaman Ijaz Siddiqui
for their contributions to this presentation.