A Fast Algorithm for Computing Doppler Introduced by Sea Surface Gravity Waves

John C. Peterson
Michael B. Porter

Heat, Light and Sound Research, Inc.
3366 N. Torrey Pines Court, Suite 310
La Jolla, California 92037
http://www.hlsresearch.com/
+001 858 457-0800

161st Meeting of the Acoustical Society of America
Seattle, Washington
Session 5aUW
Friday 27 May, 2011

Outline of Presentation

Introduction

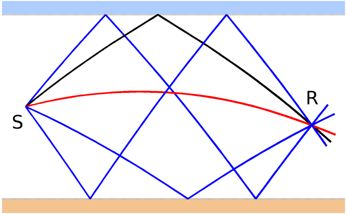
Motivation for our work

- Acoustic modem performance is *more than just transmission loss!*
- Computationally efficient algorithms for the rigorous modeling of the effects of the sound channel on a given timeseries were needed

- The VirTEX algorithm was developed to address the issues introduced by time-varying environments, and utilizes post-processing of the output from contemporary ray tracing computer programs
- Our efforts have produced two new (*more efficient*) algorithms;
  - VirTEX for Platform Motion (VirTEX Extra-Lite)
  - VirTEX for Sea Surface Motion (VirTEX Lite)

- VirTEX (Virtual Timeseries EXperiment) algorithm
  - See M. Siderius, M. Porter, JASA, vol. 124, no. 1, pp. 137-150
  - Based on post-processing of *multiple* ray tracing computations
  - Suitable for modeling of arbitrary forms of environmental motion
  - The most demanding of computational resources
- VirTEX for Platform Motion (VirTEX Extra-Lite) algorithm *(New!)*
  - Based on post-processing of a *single* ray tracing computation
  - Capable of modeling *only steady source and receiver motion*
  - The least demanding of computational resources
- VirTEX for Sea Surface Motion (VirTEX Lite) algorithm *(New!)*
  - Based on post-processing of a *single* ray tracing computation
  - Capable of modeling unsteady sea surface, source and receiver motion
  - Some restrictions on the sea surface motion

- Ray tracing methods compute N eigenrays or paths from src to rcv

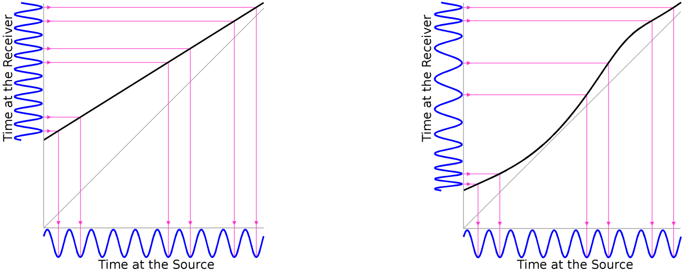


- Each path has an associated amplitude A_i and arrival or travel time τ_i
- The receiver timeseries is given by the convolution of the source timeseries $s(t)$ with the impulse response of the channel

$$r(t) = \sum_{i=1}^{N} A_i \; s(t - \tau_i)$$

- For time-varying environments, A_i and τ_i become *functions of time*

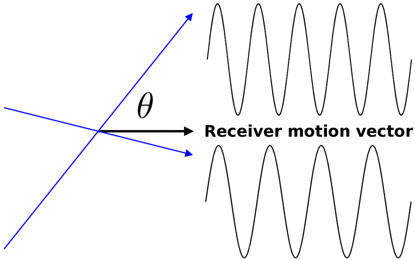
- The receiver timeseries (for a given eigenray) is found by evaluating the *inverse* of the "wall clock" arrival time $f(t) = t + \tau(t)$



(a) Steady motion (b) Unsteady motion

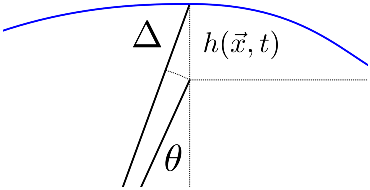
- For steady motion, this reduces to the familiar result
  - Receiver timeseries is a time stretch and shift: $r(t) = s(t_0 + \frac{t - t_0 - \tau_0}{1 + (\frac{v}{c})})$
  - Chirp Z transform can compute $r(t)$ efficiently for $t_0 = \tau_0 = 0$

- Algorithm supports *only steady source and/or receiver motion*
- Path dependent stretching factor becomes $1 + \left(\frac{v_r}{c}\right)\cos(\theta)$



- "Library" of pre-stretched waveforms (using Chirp Z transform)
- Compute convolution as before, but using pre-stretched waveforms
- The *least demanding* of computational resources

- The algorithm supports unsteady source, receiver, and sea surface motion (with some caveats, restrictions)
- The essence of the algorithm is to construct a table of values of $f(t_i) = t_i + \tau(t_i)$, by introducing first order corrections that account for the sea surface, source and receiver motion

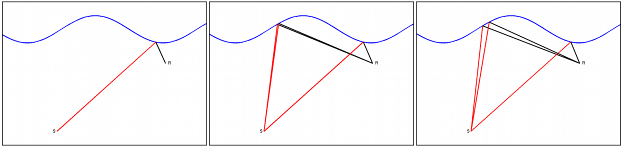


- For surface height given by $h(\vec{x}, t)$, the (first order) change in the path length is given by the expression $\Delta(t) \approx h(\vec{x}, t) \cos(\theta)$
- Step along ray, correcting $\tau(t)$ by $2\frac{\Delta(t)}{c}$ at each surface interaction

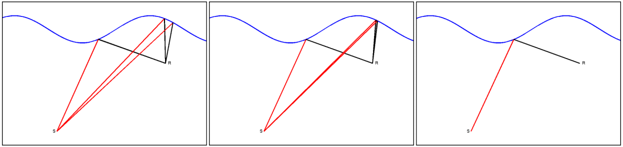
Practical Algorithms for Modeling Time-Varying Environments

The VirTEX for Sea Surface Motion (VirTEX Lite) Algorithm - Continued

- Provides good agreement for cross-swell geometry
- The algorithm can breakdown in *very high sea states*
- Can't address situations where eigenray(s) appear and disappear



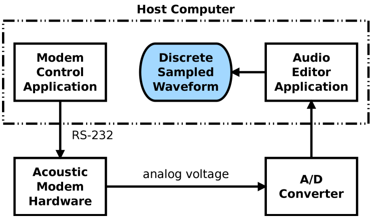
(a) Eigenrays appearing as time progresses



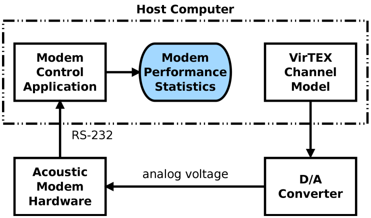
(b) Eigenrays disappearing as time progresses

- Generally not an issue unless source and receiver very near surface

- HIL procedure for testing hardware (black box) acoustic modems
- Transducer is replaced by A/D converter (a)
- Hydrophone is replaced by D/A converter (b)
- Environment is replaced by VirTEX channel model



(a) Capture of Modem Waveform

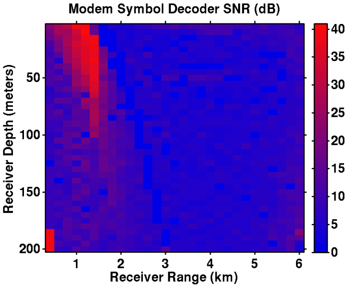


(b) Playback of Received Waveform

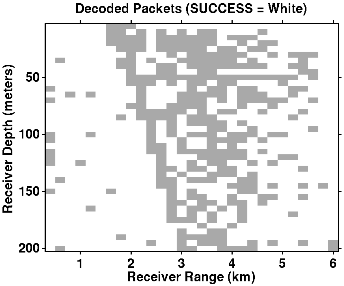
Applications to Acoustic Communications

Modem Sensitivity to Source, Receiver Position using VirTEX for Platform Motion

- Center frequency of 10 kHz
- Water depth of 500 m, reflective bottom
- Grid of receiver positions, moving 1.5 m/sec *towards source*
- Source is fixed at depth of 50 m



(a) Modem Symbol SNR (dB)

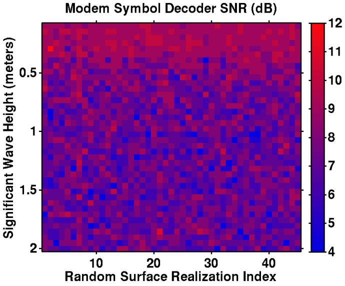


(b) Decoded Packets

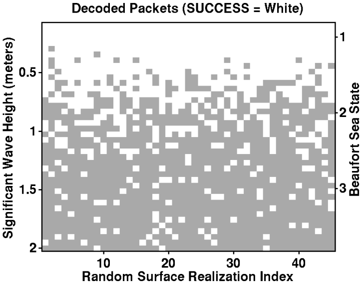
Applications to Acoustic Communications

Modem Sensitivity to Significant Wave Height using VirTEX for Sea Surface Motion

- Center frequency of 10 kHz
- Fixed source at depth of 75 m
- Fixed receiver at depth of 50 m
- Source and receiver separated by 500 m (both in strong surface duct)
- Multiple surface realizations for a range of significant wave heights
- JONSWAP sea surface spectrum, down-swell geometry



(a) Modem Symbol SNR (dB)



(b) Decoded Packets

Summary and Conclusions

- Two variants of the VirTEX algorithm were presented that have more modest computational resource requirements (in exchange for some restrictions on the forms of environmental motion)
- These algorithms are well suited to "what if" performance simulations
  - Testing signal processing algorithms for acoustic communications
  - Hardware-in-loop testing of commercial "black box" modems
  - Pre-deployment or pre-experiment simulations
- Acoustic modem performance is *more than just transmission loss!*
- Available in the next release of BELLHOP / Acoustics Toolbox
- `http://oalib.hlsresearch.com/Rays/index.html`