Low Frequency Beamforming in Shallow Water Environments

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Abstract

Beamforming is a spatial filtering method that uses the ray theory to estimate the arrival angle from the array recordings that fails when water depth is smaller compared to the acoustic wavelength (shallow-water low-frequency propagation).

Theory

In shallow water, the underwater sound propagation is modeled by normal-modes theory in which each mode propagates at a different incident angle and the total field is composed of a discrete sum of the propagation modes excited at the broadcast frequency.

$$P(\omega,r,z) = -i\pi e^{i\omega t}\sum_{m=1}^{M}\psi_m(z_s)\psi_m(z)H_0^{(2)}(k_{rm}r)$$

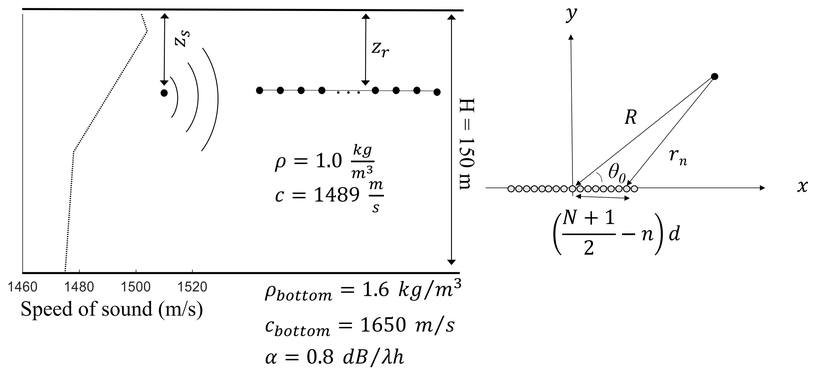
$$= \frac{ie^{-\frac{i\pi}{4}}}{\rho\sqrt{8\pi r}}\sum_{m=1}^{M}\psi_m(z_s)\psi_m(z)\frac{e^{ik_{rm}r}}{\sqrt{k_{rm}}}$$

Beamforming techniques use array recordings to determine wave propagation directions by relying on time delays to determine weights from a plane-wave signal model and is given by:

$$b(\theta,\omega) = \sum_{}^{N} P(\omega,r_n,z_n)e^{-ik\left(\frac{N+1}{2}-n\right)dsin\theta}$$

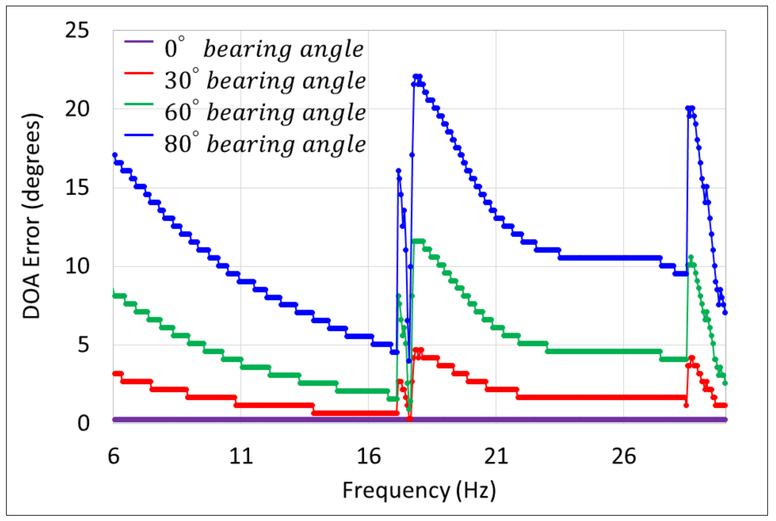
Simulation

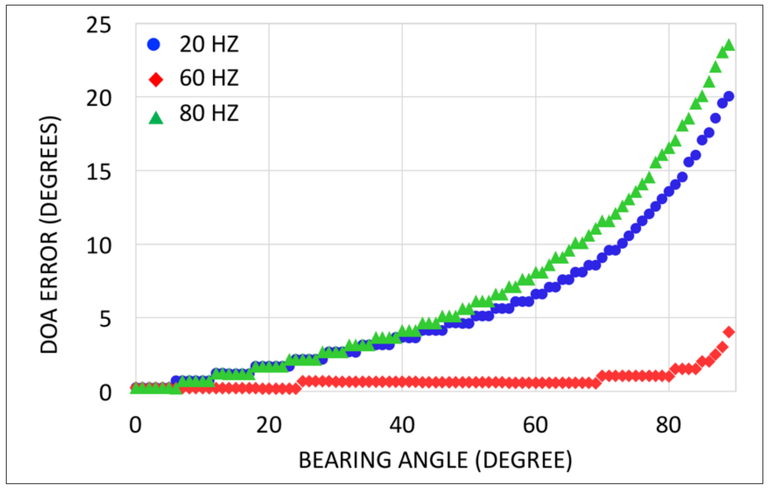
The normal mode propagation algorithm KRAKEN (Porter and Reiss, 1984) is used to propagate a single frequency signal through a two-layer waveguide.

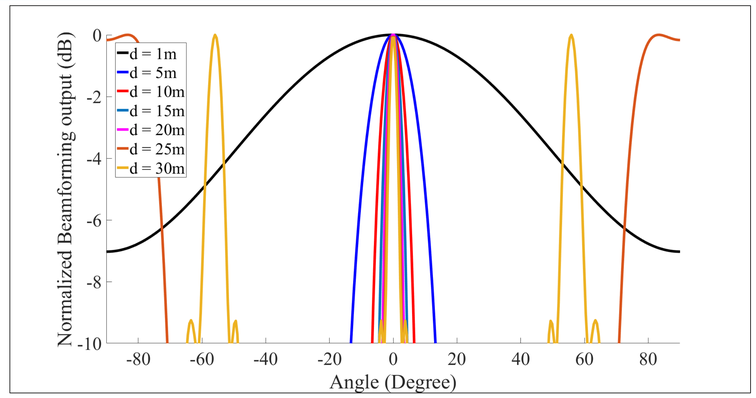


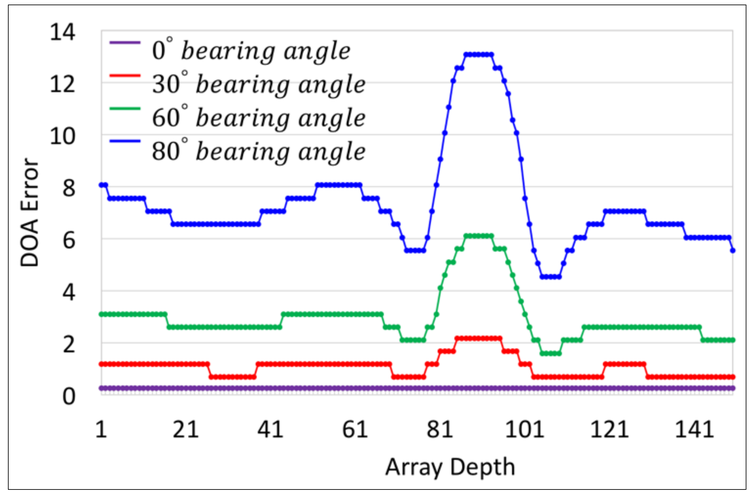
Results

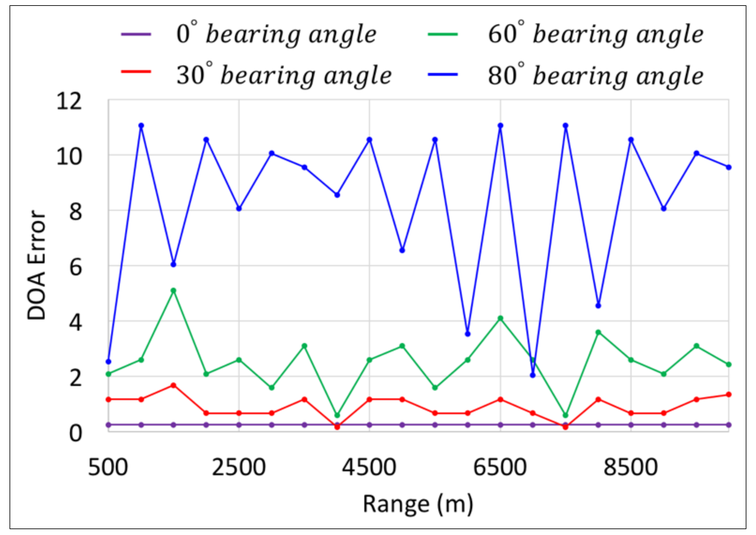
Simulation is used to study the effects of the number of modes, bearing angle, element spacing, source/receiver depth, and range on beamforming.











Conclusion

In shallow water, beamforming strongly depends on array geometry, frequency, sensor depth, range, and bearing angle.