Parametric Ultrasonic Arrays for Ocean Acoustic Waveguide Remote Sensing (OAWRS) in the Great Lakes and Other Challenging Environments

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Background

Ocean Acoustic Waveguide Remote Sensing (OAWRS) is an acoustic remote sensing method with the potential to simultaneously and instantaneously monitor fish concentration across large areas of aquatic bodies. OAWRS operates by sending out linear frequency modulated (LFM) signals from a submerged acoustic source while the water surface and seabed act as an acoustic waveguide for sonic propagation. Acoustic signals reflect off schools of fish and are collected by a receiver array, which are processed to determine fish location and concentration as seen in Figure 1. Researchers show that fish species can be differentiated based on their frequency-dependent "signature" at different LFM center frequencies [2].

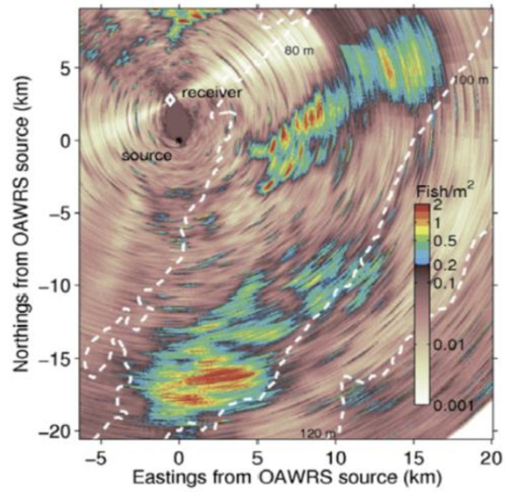

Figure 1: OAWRS output showing location of fish density [1]. The white dashed lines represent bathymetry contours.

Challenges with Current OAWRS Configuration and Size

1. Side Lobes in a Narrow Acoustic Waveguide: Side lobes are an unwanted noise pattern caused by acoustic energy radiating at angles away from the main direction of propagation. In shallower bathymetry the acoustic waveguide is narrowed which increases the reverberation of side lobes [3]. This reverberating energy arrives at the receiver alongside the signal of interest which decreases the signal to noise ratio (SNR). To counter this effect in shallower bathymetry, a higher directivity source could be used to minimize these unwanted echos. Dr. Gan within MTU's MAE department has identified a technology, parametric ultrasonic arrays (PUAs), that could be used to create low frequency sound waves with very high directivity [4]. This more compact method could eliminate the large wavelength transducers currently used in OAWRS.

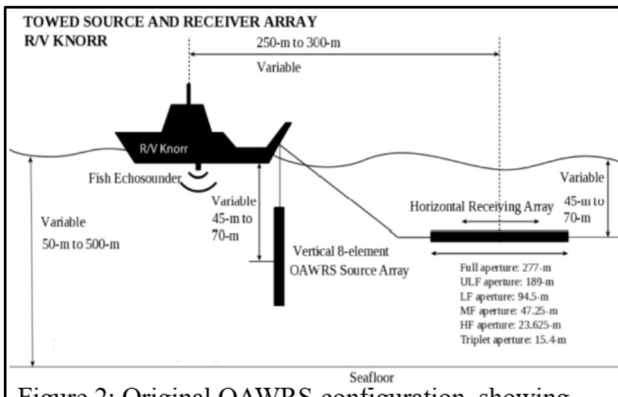

Figure 2: Original OAWRS configuration, showing details of source and receiving array [2].

2. Draft Depth: The current vertical source array, seen in Figure 2, has a large draft that challenges its implementation in non-oceanic conditions. A horizontal or more compact source array could be more suitable for use in shallow bathymetry conditions. It could also enable implementation with smaller vessels, including autonomous ones.

3. Surface Ice: The current ship-towed pair of arrays is not suited for continual testing in the presence of surface ice. While the current OAWRS method has been demonstrated in ice-free conditions [2], the development of a more compact source and receiver array could enable the use of autonomous underwater vehicles (AUVs) or unmanned surface vessels (USVs) as a more capable testbed for long-duration deployment in these environments. It could also be permanently installed near a point of interest for long term monitoring.

Research Goals and Approach

My goal is to explore how advanced acoustic technologies and a refined source-reviever package can be applied to the OAWRS method. Specifically, this refined package will address the shallow, complex bathymetry and surface ice that is found in the Great Lakes and other challenging environments. My hypothesis is that a highly directional source technology configured as a more compatible package would be an improved testbed for this application. The refined OAWRS hardware package that is developed through this project will complement the software work of my mentor, Dr. Lucas, who has a specific focus on developing acoustic propagation modeling and OAWRS signal processing.This project will have the following five main phases.

Problem Understanding: Recently Dr. Lucas worked on a pilot simulation project studying the use of OAWRS in the Great Lakes [5]. These simulations, paired with his connections to topical experts in the field will guide project constraints and objectives.

Literature Review: I plan to explore key domains of this project, including PUAs, submerged enclosures, hydrophones, and AUV platforms. Following Dr. Gan's idea I've taken proactive steps to confirm that PUAs have the potential to replace and improve upon the large wavelength transducers as seen in the current OAWRS source arrays [6].

Concepting and Design: The OAWRS sensor array design process would incorporate finite element analysis and modal simulation to inform in-process design decisions. I also plan to leverage Dr. Gan's experience with electric propulsion systems, electrical acoustics hardware, and hydroacoustics modeling as I strive to create novel and effective concepts.

Prototype Manufacture: MTU resources like the MAE machine shop will be used to construct the hardware prototype. External funding for a physical prototype has already been secured by Dr. Lucas.

Validation: The fully developed hardware would first be tested in the MTU wave tank facility as a controlled environment for initial sensor development. Repeatable waves will allow the study of surface reflections, which greatly impact sensor performance. The bottom of the wave tank is also reconfigurable to model complex shallow water bathymetry where OAWRS has not yet been extensively tested. As the project progresses into open water testing, the hardware could be integrated onto one of the autonomous platforms currently operated in Lake Superior that would enable longer-term monitoring, such as the Saildrone operated by USGS or the Ocean Infinity Armada C-Worker 8 autonomous surface vessel operated by the GLRC.

External Interest

This project was inspired by conversations with Pete Esselman, chief scientist at the United States Geological Survey, where he asked if the OAWRS method could be adopted for lake environments that experience ice coverage. This research also aligns well with active naval funding calls, especially at the ONR (Office of Naval Research), who explicitly state their interest in underwater acoustics in challenging environments such as shallow and/or icy waters [7]. Ultimately an OAWRS system that can operate in shallow, complex bathymetry and under ice would have dual-use civilian and defense applications.

References

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[3] D. D. Sidorov, V. G. Petnikov, and A. A. Lunkov, "Broadband Acoustic Field in a Shallow-Water Waveguide with an Inhomogeneous Bottom," Acoustical Physics, vol. 69, no. 5, pp. 699–709, Nov. 2023, doi: 10.1134/S1063771023600663.

[4] Zhou, Hanyun, S. H. Huang, and Wei Li. "Parametric acoustic array and its application in underwater acoustic engineering." Sensors 20.7 (2020): 2148.

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Personal Interest

I got into audio hobbies about 5 years ago when I built my first set of speakers. Since then I have leveraged resources on MTU's campus to explore more complex and experimental acoustics topics. I am currently the chair of Michigan Tech's Audio Engineering Society and in Spring 2025 I led an AES team that built the world's largest rotary subwoofer. This very niche type of speaker plays 1-20hz frequencies (infrasonics) at amplitudes large enough to shake buildings and simulate earthquakes. I had a lot of fun with this project and it was really my first step into an audio project that developed something completely new. Another project I've enjoyed in the past was designing and building an underwater drone that captured pictures of Grand Haven Michigan's pier structure. I see this research project as a continuation of the personal projects I am passionate about and as a way to continue developing my technical skills as an engineer.

I will be graduating with my bachelors degree in December 2026 and have plans to continue on to a project based masters degree at Michigan Tech. Effectively, my last undergrad semester would be spent working on research through the URIP program that would lay the foundation for my project based masters. Dr. Lucas and Dr. Gan in the MAE department are both faculty that I have a good relationship with and would be interested in working with into the future, especially related to a masters degree.