Development of Mid-Frequency Multibeam Sonar for Fisheries Applications

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LONG-TERM GOALS

The long-term goal of this program is to investigate the utility of mid-frequency (~10 kHz) acoustics to detect, enumerate, and identify pelagic fish distributions.

OBJECTIVES

Objectives of this research include: comparisons of fish backscatter models, models of mid frequency sound propagation, development of a mid-frequency multibeam sonar, and backscatter measurements using splitbeam echosounders and the multibeam sonar.

APPROACH

Our strategy integrates biological and physical model predictions with field measurements and will combine results in computer visualizations and animations. Efforts are directed in three primary areas: sound propagation modeling, fish backscatter modeling, and mid-frequency multibeam development and field measurements.

Sound propagation modeling efforts focus on continental shelf environments in the northeast Pacific including the Gulf of Alaska and along the Washington coast. Effects of multi-path propagation, water depth, substrate type, substrate and surface roughness, and range dependence on propagation, including temporal and spatial variability in the environment will be modeled.

Sound propagation characteristics will be combined with anatomical models of fish to examine backscatter from individuals and aggregations of fish. This approach will enable us to model potential detection strategies for different types of fish, their behaviors, and to predict variability in fish aggregation backscatter. Backscatter predictions for individuals within aggregations (i.e. the forward problem) will be compared to *in situ* measurements.

To measure synoptic distributions of fish schools we will collect mid (10 kHz) and high (38 kHz) backscatter data from fish aggregations using a multibeam sonar and a splitbeam echosounder. The sonar is expected to detect fish at kilometer scale ranges while the echosounder will be used to detect aggregations and individual animals at ranges of hundreds of meters.

WORK COMPLETED

The mid-frequency sound propagation modeling effort focused on the effect of the acoustic waveguide on echo returns from fish schools. The approach examines how reverberation from fish might be masked by reverberation from the bottom or the surface. A full-wave acoustic propagation model was modified to perform sensitivity studies of multi-paths in acoustic waveguide environments. Simulations have used different source depths, water depth, and different bottom types.

To increase understanding of the interaction between sound propagation and the reflection of sound by biological targets, a computer simulation application was developed to visualize individual and group backscatter from known populations of fish.

The design and fabrication of the Pelagic Imaging Mid-frequency Multibeam Sonar (PIMMS) system was completed in summer 2006. Initial testing and calibration of the PIMMS occurred at the APL acoustic calibration facilty in July 2006. The first gear trials were conducted in the Gulf of Alaska from August 11 to August 13 aboard the NOAA RV Miller Freeman. Four sampling stations were occupied in the Chiniak trough for a total data collection time of approximately 20 hours. Deployments of a side-looking, 38 kHz echosounder and midwater trawls were also conducted to provide backscatter and target verification data for comparison to the sonar data.

Storing all laboratory, field, and modeling data in a central location will now be possible with a new data stacker. A 2.9 Tb RAID 6 array has been assembled and integrated into the UW Fisheries Acoustics Research Laboratory LAN. Access for all cooperating researchers will be permitted through a virtual private network (i.e. VPN) and firewall.

RESULTS

Sound propagation modeling has tested bottom types from soft clay and silt to gravel and rock. The model solves for the Green's function from the source to a target (single fish as a point source) located at all ranges and depths set in the simulation. As an illustrative example, consider a silt bottom, a constant bottom depth of 90 m, and a source at 50 m. Figure 1a shows the transmission loss for this waveguide for a 10 kHz carrier frequency. Most of the energy interacting with the bottom penetrates and is absorbed, and the resulting transmission loss field plot is nearly a perfect Lloyd mirror pattern. Modal interference is possible near the surface and near the bottom at greater ranges. Interference can bias echo returns from biological targets. Figure 1b illustrates the bias estimate map showing potential error in estimating biomass from a PIMMS reception. The potential maximum bias at a given range over all depths is less than 10 dB, and is well concentrated toward the surface and bottom for water depths deeper than about 80 m.
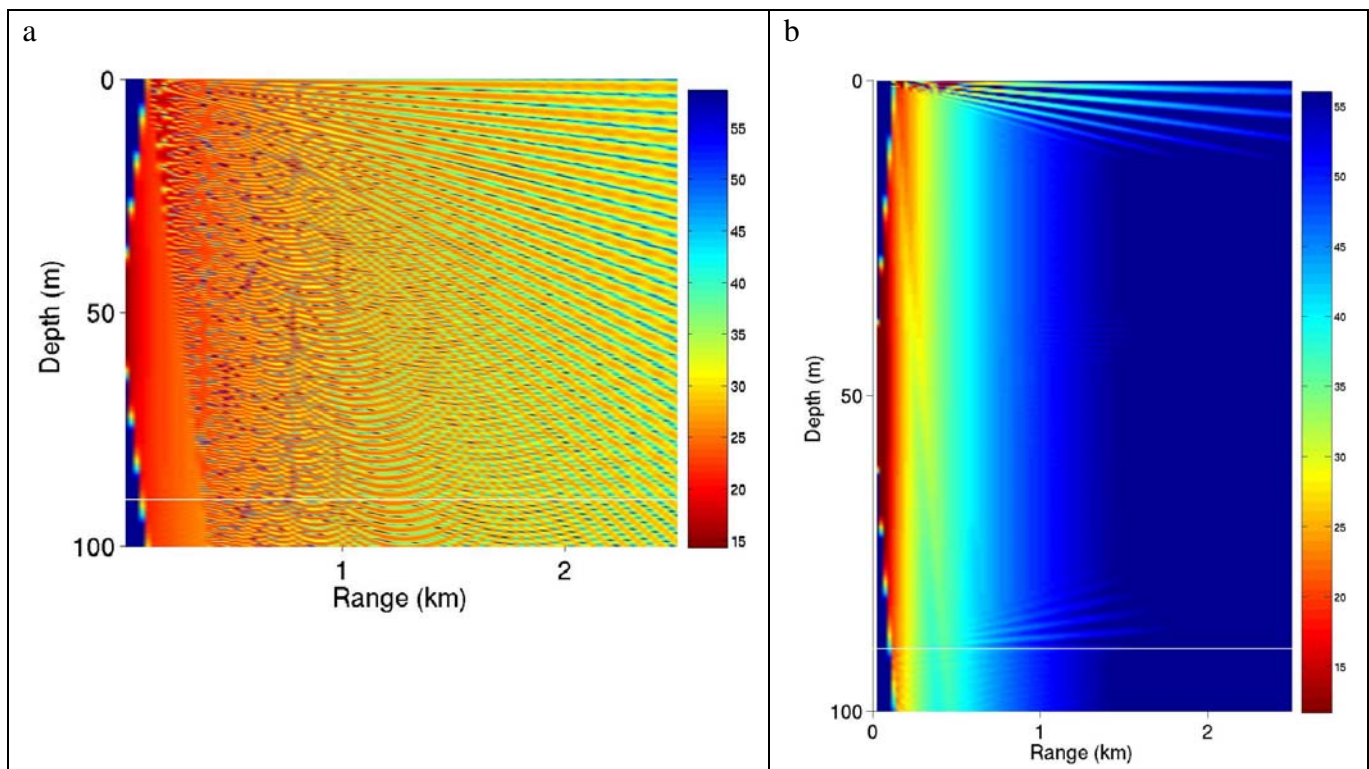
Figure 1. a) Transmission loss field plot using 10 kHz source at a depth of 50 m in a 90 m water column (white line) with a soft silt bottom, b) Bias map derived from the source and environment.

Ensemble and individual acoustic reflectivity (i.e. backscatter) from fish within an acoustic beam can now be visualized and tracked in a single computer application (Fig. 2). In the fish school echogram visualization the position of each fish is calculated for every animal in the model domain and the orientation is extracted for those within the user-defined, acoustic beam. The corresponding backscatter is extracted from a Kirchhoff-ray mode predicted backscatter matrix indexed using pitch, yaw, and roll orientations, and then the fish is rendered in the main panel to match its backscatter intensity (i.e. target strength). Backscatter from all fish within the beam is integrated and plotted on a real-time echogram. Initial work on extinction coefficients is depicted in a second echogram to illustrate the effects of packing density and shadowing on ensemble backscatter. Two fish can be tagged to track individual target strengths at the same or two additional acoustic frequencies. The difference between backscatter intensities (i.e. target strength differencing) is plotted to illustrate potential fish size or species discrimination.
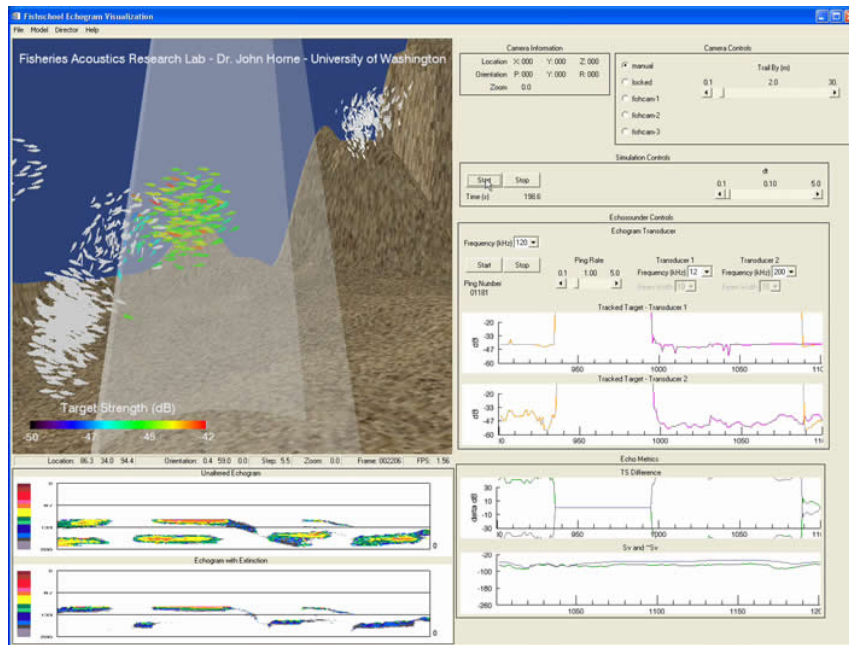
Figure 2. Screenshot of the fishschool echogram visualization application. Fish in the acoustic beam are colored coded for target strength depending on their size, orientation, and position in beam. Integrated energy is displayed in echograms below the main visualization panel. Transducer frequencies are controlled from the upper right boxes. Two fish can be tagged and their target strengths can be tracked (lower right graphs).

The PIMMS system is approximately 1.5 m in diameter and is deployed from a standard CTD winch and cable. The system consists of a circular receiving array (64 data channels, ~5° resolution over 360°) and a separate transmitting line array (16 elements). The resulting transmit beam configuration is 9 degrees vertical and 360° horizontal. The vertical imaging resolution of the system is defined by the intersection of the receiver and transmitter beams (Fig. 3). The receiver simultaneously records all 64 dipole receiving elements and stores the data internally. The data acquisition control processor runs Linux and communicates to the top-side controller (laptop) via 10baseT Ethernet.
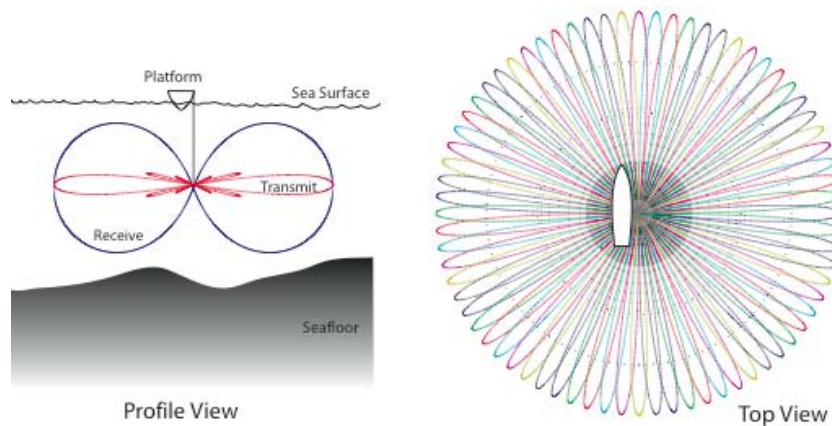

Figure 3: Geometry and imaging volume of PIMMS illustrating the transmit and receive beam patterns.

The transmitter is a custom design 8 channel pulse width modulation (PWM) design capable of generating arbitrary transmit signals on 8 channels which enables transmit beam steering. Vertical imaging resolution is achieved by steering the narrow transmit beam in elevation or by moving the whole system up and down through the water column like a profiler (Fig. 4).

Figure 4. The Pelagic Imaging Mid-frequency Multibeam Sonar (PIMMS) being deployed.

Preliminary analysis of acoustic data taken in August 2006 shows the detection of potential fish aggregations at horizontal ranges up to 300 meters from the ship. Figure 5 illustrates beamformed
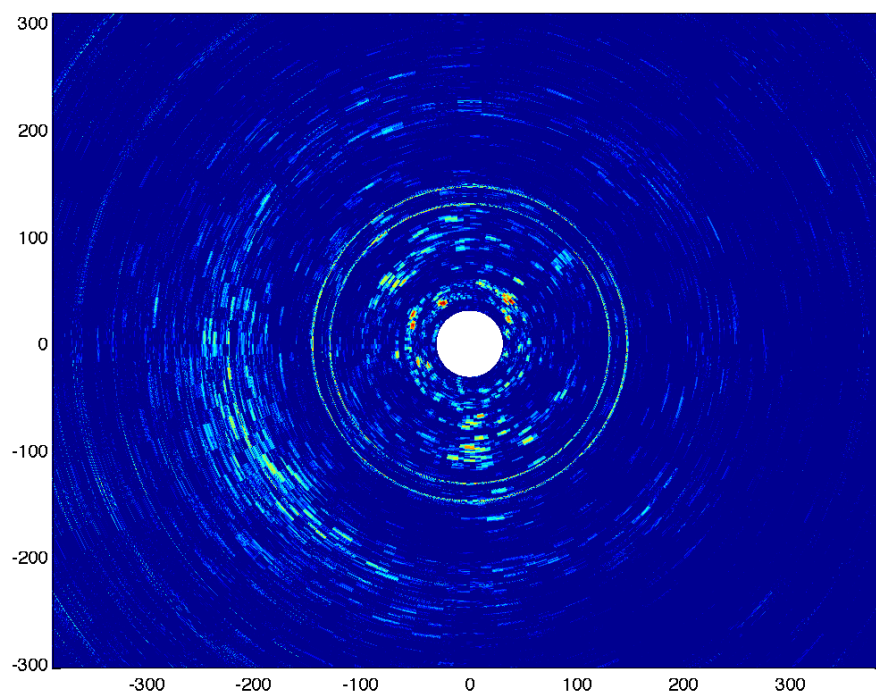

Figure 5. PIMMS image of potential fish aggregations in the Gulf of Alaska. The water depth at this location was 100 meters.

backscatter from the water column created from a single PIMMS ping, with ~5 degree horizontal beams combined to image a 360° sector. PIMMS is located at the center of the radial image. Backscatter intensities increase from blue to red.

Figure 6 illustrates a closeup view of backscatter targets within a 100 m range of the sonar. Aggregation diameters are approximately 10 meters or less in the horizontal scale. Beyond 100 m, targets are not as well resolved, although they are believed to be fish aggregations. This degradation in backscatter imagery as a function of range is expected and further data analysis to recover longer range targets is ongoing. Several techniques are being employed to recover long range data including high resulution beamforming, the use of longer frequency modulated (LFM) pulses which improves the signal to noise ratio in the waveguide backscatter, the use of matched filtering methods, and modeling waveguide backscatter to better understand the limitation of horizontal imaging in a waveguide.
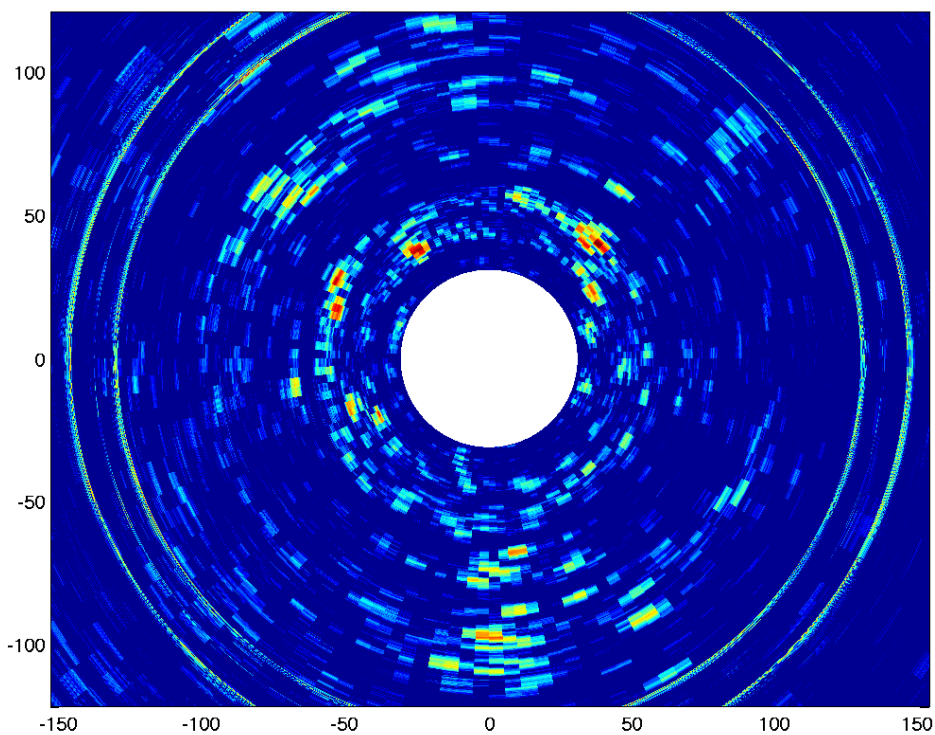

Figure 6. Closeup of PIMMS image of potential fish aggregations in the Gulf of Alaska showing higher image resolution for backscatter targets within a 100 meters radius of the sonar. The sonar is located at the center of the image.

IMPACT/APPLICATIONS

National Security
The multibeam system (PIMMS) is a sonar technology that could be used to image anthropogenic and biologic objects in any water column.

Economic Development
The multibeam system (PIMMS) potentially provides a tool for synoptic (i.e. seconds) mapping of fish distributions at intermediate spatial scales (i.e. kilometers).

Quality of Life
The use of synoptic imaging tools should increase the ability to design acoustic surveys to accurately estimate population abundances of commercially important fish and zooplankton species. This technology may also be incorporated as part of an ocean observing system to monitor ecosystem dynamics.

Science Education and Communication
A wiki has been created for collaborative efforts among the PI's. A public web site is under development to document results of the project.

TRANSITIONS

Economic Development
Components of the PIMMS system were manufactured by the University of Washington's Electronic Engineering Department to increase efficiency of production.

Quality of Life
The first testing of the PIMMS system was conducted in conjunction with a NOAA Alaska Fisheries Science Center walleye pollock – fisheries interaction survey.

RELATED PROJECTS

The multibeam sonar developed in this project was also deployed in the mid-Atlantic Bight in support of the NOPP sponsored project entitled, "Novel Acoustic Techniques to Measure Schooling in Pelagic Fish in the Context of an Operational Coastal Ocean Observatory."

AWARDS

John K. Horne, University of Washington, H. Medwin prize in Acoustical Oceanography, Acoustical Society of America.