THE APPLICATION OF 3-D VISUALIZATION TECHNOLOGY TO PELAGIC FISHERIES ASSESSMENT AND RESEARCH

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ABSTRACT

Traditional acoustic approaches to fish biomass estimates have relied upon single beam echo sounders that sample a relatively small volume of the water column within the survey area. Mean transect values after bottom removal are extrapolated to provide an estimate of number or biomass within a survey area. Conversely, multi-beam sonars, which are commonly employed to collect detailed bathymetric and seafloor-type data, are designed to gate out mid-water returns. For fisheries, the movement from single to multi-beam acoustic surveys provides a mechanism to greatly enhance the area of coverage and provides a new suite of tools, both 2D and 3D, for the exploration, analysis and presentation hydroacoustic data. This paper describes initial studies in our transition from single to multi-beam applications, the types of equipment investigated, the limitations of several acoustic systems examined and how geomatics and 3-D visualization is being used to enhance our knowledge of pelagic fish schools. Early results indicate that multi-beam sonars and their associated software are powerful tools for assessing fish stocks, investigating fish school behavior, habitat preferences and addressing the question of vessel avoidance. As the technology improves so will the capability to investigate and to incorporate additional multi-parameter data such as water properties and bottom type.
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1. INTRODUCTION AND BACKGROUND

Scientific surveys in support of fisheries assessment typically consist of standardized field programs involving stratified trawls and/or acoustic measurements that use relatively narrow-beam vertical-incidence echo sounders. The accuracy of each of these approaches is severely limited by the need to extrapolate from small sample sizes and an uncertain knowledge of how sampling techniques influence the estimates. In addition, the natural behavior of the fish is an unknown affecting both trawl and acoustic surveys. Variations in the natural behavior may bias estimates through variations in availability, i.e., annual or seasonal changes in the vertical distribution of fish as well as through changes in organizational structure that affect the "catchability, i.e. whether fish are distributed as individuals, patches or schools. The issue of active avoidance is also a key to understanding biomass estimates based on either acoustic or trawl measurements. If fish react to an approaching vessel with a horizontal or vertical avoidance, a dilution of the actual fish density may occur (Misund, 1997 and references therein). In addition, there have been observations of substantial and variable avoidance of pelagic fish to trawl noise (Ona and Godo, 1990). At the root of many of these problems is the limited spatial coverage of the trawls and the trade-off between spatial coverage and resolution that limits the acoustic surveys.

Recognizing the need to increase areal coverage without compromising spatial resolution, Bodholt (1982), Misund and Algen (1992), Gerlotto et al., (1994), Hafsteinsson and Misund (1995) and others pioneered the use of multibeam or sector scanning sonars to address the critical issues of fish behavior and vessel avoidance. Given the constraints of the available systems the approach taken by these investigators was to digitize the video images produced by the sonar and use these digitized images as the basis for subsequent analysis. In late 1997 a new multibeam sonar was introduced that permits the acquisition of the entire digital data stream and thus has the potential to allow for real-time or near-real time 3-D visualization of the entire ensonified water column several hundred meters to either side of the vessel. In a collaborative effort also involving the sonar manufacturer (Kongsberg-Simrad), the fishing industry, and the Canadian Dept. of Fisheries and Oceans, researchers from the University of New Brunswick's Ocean Mapping Group have developed a prototype software toolkit for the interactive 3-D visualization of multibeam sonar fisheries data. This paper will describe the approach we have taken, the present capabilities and initial field results from the system, as well as look at directions for future work.

1.1 Multibeam Sonars and the UNB Ocean Mapping Group

Our ability to explore the oceans has been inextricably linked to the evolution and development of sonar systems. Echo sounders (used both for measurement of depth and for fisheries work) have evolved over the years from primitive instruments that could
barely discern a faint echo from the seafloor to sophisticated systems with complex signal processing algorithms that result in extremely high signal-to-noise ratios and target resolution. The earliest echo sounders produced vertical beams that were very broad (typically 30 to 60 degrees); while the travel time (and thus range if sound speed is known) to a target could be easily be measured, the lack of angular resolution within the beam meant that the target could be anywhere within the beam footprint (an area with a diameter of .6 to 1.7 times the range). To resolve this problem, narrow beam (less than 10 degrees) echo sounders were developed providing much greater lateral resolution but the tradeoff being the ensonification of a much smaller volume of water. The ability to achieve both large areal coverage and high lateral resolution (through angular discrimination) came with the development of mechanical sector scanning sonars and then, in the early 1970's with the development for the military of multibeam sonars.

A multibeam sonar typically uses multiple elements within a single array or orthogonal transmitting and receiving arrays to produce a transmit pulse that is narrow (1 to 3 degrees) in one direction (typically the fore-aft direction) and very broad (typically 90 to 180 degrees) in the opposite direction (typically athwartships). Electronic beamforming is used to produce a number (typically somewhere between 48 and 128) of simultaneous receive beams that are narrow (typically 1 to 3 degrees) in the athwartships direction and relatively broad (typically 10 to 20 degrees) in the fore-aft direction. The receive beams intersect the transmit beam to produce 48 to 128 individual areas of ensonification that are the cross product of the transmit and receive beam widths (typically 1 to 3 degrees by 1 to 3 degrees). Thus the system has large areal coverage (the swath width is 7.5 times the range with a 150 degree system) while maintaining the angular resolution of an extremely narrow beam sonar (1 to 3 degrees). In contrast to a sector scanning sonar, the entire arc of the multibeam transmit pulse is imaged each time the sonar pings resulting in complete coverage at rates that can, at longer ranges, be hundreds of times faster than a scanning sonar (Fig. 1).

Fig 1. Typical geometry of bottom tracking multibeam sonar
Over the past 20 years many manufacturers have introduced multibeam systems working at frequencies from 12 kHz (for deep water) to 455 kHz (for shallow water) but given the tremendous amount of data produced by these systems, almost all of these systems are designed to record only the returns from the seafloor. Considering only the seafloor returns, a high-frequency multibeam system working in shallow water can collect more than 15 million soundings in an hour; many systems also record the backscatter of the return and in shallowest mode can gather more than 400 Mbytes of data an hour. While this data density presents a difficult challenge to the data processor, it also presents tremendous opportunities inasmuch as it allows us to take advantage of modern data visualization tools that can represent the data in new ways with unprecedented detail.

In the late 1980’s, and early 1990’s, the Canadian Hydrographic Service acquired several multibeam echo sounders and quickly realized that the tremendous density of data generated by multibeam sonars presented serious challenges in terms of data management, processing, verification and interaction. The CHS came to the University of New Brunswick to seek assistance in developing a suite of data processing tools. This request led to the formation of the Ocean Mapping Group and the NSERC Industrial Chair in Ocean Mapping with a mandate to develop new and innovative techniques and tools for the management, processing, visualization and interpretation of ocean mapping data.

The tremendous density of data generated by multibeam sonar system does indeed present serious data processing and handling challenges, and in response to these challenges, the Ocean Mapping Group has developed a suite of software tools for the real-time processing, analysis, and editing of multibeam sonar data. The tremendous data density, however, also provides the ability to convert the numeric data into image data and thus take advantage of the opportunities offered by scientific visualization. In order to facilitate the exploration and analysis of the massive data sets generated by multibeam sonars, the Ocean Mapping Group has developed a suite of scientific visualization tools that allow for the interactive 3-D visualization and exploration of large ocean mapping data sets in a simple and intuitive manner.

The combination of dense seafloor coverage provided by multibeam sonar systems and visualization techniques has revolutionized the way in which we study the seafloor. We no longer need to present bathymetric data as discrete soundings or interpolated contours, but rather we can create full digital terrain models and then use color coding, artificial sun illumination, shadow generation and texture to create natural and realistic-looking 3-D depictions of the seafloor (Fig 2.). Much like the first aerial photographs or satellite images, multibeam sonar data has provided an unprecedented perspective of seafloor topography and thus new insights into the understanding of seafloor processes. More recent developments in multibeam sonar systems have allowed the simultaneous collection of seafloor backscatter data. These data provide insight into the nature of the seafloor (its roughness and/or composition) and when combined with the detailed bathymetric data collected with multibeam sonars offer the opportunity to present thematic maps of the seafloor.
1.2 Applications to Fisheries Research

The ability to collect, display and interactively explore detailed bathymetric and seafloor-type data clearly has applications in studies of fisheries habitat. We have begun to use this approach for habitat studies of a number of ground-fish species and in direct support of the scallop fishery (i.e., 3-D seafloor maps provided directly to the fishermen). In response to the growing pressures on pelagic fisheries however, the Canadian Hydrographic Service and the Dept. of Fisheries and Oceans asked the Ocean Mapping Group to explore the applicability of multibeam sonar data to the direct mapping of mid-water targets.

1.2.1 Fisheries Geomatics:

Given the background and experience of the Ocean Mapping Group, the approach taken to the application of multibeam sonars to fisheries problems was a "geomatics" approach. Geomatics is the field of study related to the measurement analysis, management, storage and display of spatial data. Our initial focus in analyzing mid-water multibeam data was its visualization and display. In developing these tools we hope to directly address questions of fish school dynamics and vessel avoidance as well as define the density and volumes of fish schools; future efforts will focus on target discrimination (particularly for demersal fish as multibeam sonars resolve near-seafloor returns much more robustly than vertical incidence echo-sounders) and target classification.
In our initial investigation of the applicability of multibeam sonar to mid-water fisheries problems, we quickly learned that most multibeam sonars are designed from the bottom up to gate our mid-water returns. On the other hand, fisheries sonars which are designed to display mid-water returns, are not typically designed for the digital acquisition and data storage needed for visualization. To resolve this problem we began a collaborative project with Kongsberg-Simrad-Mesotech. In the short-term they would modify an existing sector scanning sonar to allow us a digital data stream from which to develop visualization algorithms, and in the long-term, a true multibeam sonar would be developed that would provide digital mid-water return data.

1.2.2. 3-D Visualization:

Traditionally sonar displays have presented a 2-dimensional image of relative target strength (often color coded) vs. range in a plane (usually a vertical plane beneath the vessel but with tiltable sonars, other planes can be presented). With the advent of omnidirectional and multibeam sonars, the displays are still 2-D slices though the choices for the sector presented are much greater. 2-D displays are presented because they are easy to produce in real-time. The presentation is, however, much less than intuitive as the observer is forced to attempt to mentally integrate these 2-D pictures into the actual 3-D distribution of targets. Our approach is to take advantage of recent developments in graphics hardware as well as our experience with 3-D visualization and present a fully georeferenced 3-D display of the acoustic targets. Such visualization presents information on the complete distribution of targets (within the ensonified area) in a natural and intuitive way providing direct information on fish behavior, school dynamics and avoidance and allows researchers to quickly determine if their experimental strategy is appropriate for a given set of circumstances.

2. SYSTEMS AND FIELD WORK

In developing these tools we have worked with a number of sonar systems including vertical incidence echo-sounders (Biosonics), a Simrad-Mesotech MS-900 sector scanning sonar and finally a true multibeam, the Simrad-Mesotech SM-2000. We will first briefly describe the nature of these sonars and their mode of deployment and then discuss the approach to presenting the data as true 3-D displays.

2.1 MS-900

Our initial work focused around a modified Simrad/Mesotech MS-900 sector scanning sonar. This compact sonar, originally designed for imaging and pipe-tracking, operates at 330 kHz (5 - 250 m range) with a 100 msec. pulse length, and a 1.9 x 25 degree beam that scans in 1.3 degree increments. A complete 180 degree scan takes between 17 and 34 seconds. Simrad-Mesotech modified this system to allow us to record (at 20 kHz using a custom multi-channel digitizer developed by the Ocean Physics Section of the Bedford Inst. of Oceanography) the full time series of each return as well
as navigation data (from DGPS) and information on which sector was being ensonified. While the MS-900 provided an initial dataset with which to develop 3-D visualization techniques and demonstrated both the feasibility and advantages of wide-swath coverage for fisheries research, the MS-900 is less than ideal in that the combination of the sector scanning and vessel motion leaves large portions of the water column unensonified. Thus the need for a true multibeam sonar.

2.2 SM-2000

In late 1997 Simrad-Mesotech introduced the SM-2000, a compact multibeam sonar system that operates at 200 kHz with a range of 5 - 400 m. A prototype was provided to researchers from the Dept. of Fisheries and Oceans and the Ocean Mapping Group, in order to explore its viability as a tool for mid-water fish assessment. The system provided to the Ocean Mapping Group forms 128 simultaneous beams with a swath width of 180 degrees. The beams are spaced at 1.4 degrees and the sonar footprint for this prototype was 2.4 x 20 degrees (20 degrees in the fore/aft direction [with -15 dB sidelobe suppression]). More recently, a second transmitter has been added to the system (SM2000P) which maintains the across track beamwidth of 1.4 degrees and allows for an along-track beamwidth of 1.5 or 3.0 degrees (selectable) and transmit swath widths of 120 or 150 degrees.

2.3 FIELD TRIALS

The sonar systems were tested in September 1997 and the spring of 1998 as part of herring surveys conducted by the Dept. of Fisheries and Oceans’ research vessel Teleost on Brown’s and German Banks (well-established herring spawning grounds) off Nova Scotia Canada. Standard acoustic protocol and survey design was employed with a series of randomly selected transects established for a pre-defined survey area (Melvin et al., 1998).

The sonar systems were mounted in a tow body and deployed off the starboard side of the vessel at a depth of about 15 m depth to mitigate problems of propeller wash and to decouple the sonar from vessel motion. Typical survey speeds were 5 to 7 knots and sonar ping rates were 2 to 5 pings per second. Along with the MS-900 and SM-2000 records, data was also collected with a calibrated, vertically incident (3 x 3 degree beamwidth) 120 kHz profiler (Biosonics) that was digitized with a Femto acquisition system (Melvin, et al., 1998).

3. DATA PROCESSING AND DISPLAY

For the MS-900 the time-series from each individual scanned sector was digitized at 20 kHz and stored on disk; for the Biosonics system, only those signals above a given threshold level were recorded each representing a 3x3 degree vertical scan. In each case navigational information (from DGPS) was also logged with the data and thus a relatively simple data stream of relative target strength vs range and position was available for 3-D
display. For the prototype SM-2000 system, however, the only information that was recorded was the received amplitude on each transducer element and thus the Ocean Mapping Group needed to process the data to form the 128 individual beams; the current version of the SM2000 now offers the option to record either beam-formed or raw amplitude data.

Once the beams are formed we then have a time series that represents the echo strength as a function of range for the given direction of the beam (in this case at 1.4 degree increments). Data will be presented using both the SM2000 with a single transmit/receive transducer (1.4 x 20 degree beamwidth) operating with a 180 degree swath and the SM2000P with a separate transmitter and (2.5 x 1.5 degree beamwidth) operating with a 150 degree swath. As with the other systems, navigational information was provided by DGPS and logged with the sonar data. A fixed setback was used to calculate the position of the tow body behind the vessel.

3.1 Target extraction and position determination

Our initial work took advantage of the tremendous advances in graphics hardware by using Silicon Graphics workstations as the developmental platform; subsequent work will, however, be conducted on NT-based workstations. Given a time-series of amplitudes as a function of travel-time (which is converted to range using a measured or assumed sound speed), a known beam width, and orientation for the beam and concurrent positional information for the vessel and the tow body, the position in geo-referenced space of any target in the time series can be determined. While this can be done for any “target” in the time-series, we apply a thresholding algorithm that identifies the seafloor (the strongest return in the time series) and then allows a subjective choice of the level for “significant” targets. The 3-D position and target strength for each target above the threshold and for the seafloor is then calculated and sent to an output file for display.

3.2 3-D Display

For a given ping, a ship-centered, three-dimensional coordinate scheme is established within the context of the screen display and the targets are plotted as color coded (based on target strength) 2-d polygons whose dimensions are a fixed number of sample intervals in their proper location relative to the vessel; the seafloor return is plotted as a smooth surface. For a single ping this display would look something like a standard 2-D plot provided by most sonar manufacturers. The true 3-D display results from multiple pings combined with vessel motion and the use of a moving window algorithm that provides a visual perspective that moves with the vessel. A specified number (typically 260) of pings are displayed within this window representing 1 to 3 minutes of vessel transit (depending on ping rate). This display continuously scrolls, keeping up with the vessel’s forward motion. The display of multiple ping data is done in perspective using a number of visual cues to add to the sense of 3-D (i.e. color blending which blends colors gradually into the background color as they are further from the viewers perspective). A mouse-controlled interface (widgets) allows the manipulation of the scene with 6 degrees of freedom so that it can be viewed from any
perspective. As the vessel transits, the oldest ping data is dropped and the most recent data is added resulting in a continual scrolling scene of the vessel and the targets moving over the seafloor.

4. INITIAL OBSERVATIONS AND FUTURE DIRECTIONS

The relative advantage of multibeam data and 3-D display are clearly evident from Fig. 3. Here we present a frame from a scrolling 3-D visualization collected while simultaneously profiling with a Biosonics vertical incidence profiler and the MS-900 sector scanning profiler. The acoustic footprint of each system is indicated by the green boxes intersecting the seafloor; the remarkable difference in volume ensonified is clear as the sector scanner sweeps to 75 m to either side of the vessel versus the very limited volume ensonified by the vertical profiler. It is important to note that the across track resolution of the sector scanner is better than that of the vertical profiler (1.9 deg vs 3 deg) though in this case the along track resolution of the vertical profiler is significantly better than the sector scanner. The drawback of the sector scanner in terms of unensonified volume is also evident, however. With the transition to the true multibeam (SM-2000), the entire water column is ensonified (Fig 4) and given the beamwidth available with the separate transmitter (SM-2000P), the along-track and across-track resolution is equal to or better than that of the vertical incidence sonar.

Fig. 3. Front-on view of 3-D visualization as data is being collected with both MS-900 sector scanner and Biosonics vertical profiler. Vessel is moving out of page. Footprint of MS-900 sweeps 75 m to either side of vessel as Biosonics footprint is directly below vessel (small squares). A few targets are discernable at outer ranges.
With 128 individual 1.5 x 1.4 degree beams covering a sector of 120 to 150 degrees around the vessel, we clearly are in a position to monitor the behavior of schools, if not individual fish. Our initial results have often shown avoidance behavior with schools apparently parting and/or diving as the vessel moves over them (Fig 4). While these initial observations are subjective, the combination of digital data, large areal coverage and high resolution will allow us to develop tracking algorithms that will quantitatively monitor school behavior. In particular we have developed a technique whereby the individual returns are displayed as “oriented particles” a technique that allows the targets to be viewed as individuals but with an orientation that is based on the distance to their neighbors (Li, 1996). This allows for the shape of the school to be easily discernable while maintaining the discrete character of the individuals. Algorithms will be developed for the cleaning and editing of the data as well as for determining the dimensions, volume and density of the targets.

The combination of large areal coverage and high angular and spatial resolution will also help address the key issue of biomass estimates. The small beam angles of the SM-2000P greatly enhance the chances that targets detected represent individual fish (particularly at close range) and thus greatly increase the chances of accurate Sa values. In addition, the ability to measure phase differences from discrete contiguous beams
presents the opportunity to determine the orientation of the targets (in the across track direction); the high repetition rate may allow the determination of orientation in the along-track direction. Finally, the ability to capture the entire waveform from multiple georeferenced returns, opens up the possibility of statistically robust waveform characterization for target classification.

5. CONCLUSIONS

Many of the uncertainties associated with our ability to estimate fish stock abundances can be linked directly to limitations in the spatial coverage of our sampling systems and fish behavior in response to external stimuli. In order to achieve large areal coverage, traditional hydroacoustic techniques have had to give up spatial resolution. Newly developed multibeam sonar technology, however, now allows for large areal coverage while maintaining high spatial resolution. We are taking advantage of new developments in graphics hardware, as well as our expertise in handling multibeam sonar data and in visualizing large and complex 3-dimensional data sets to develop a suite of software tools that allow the real-time or near real-time interactive 3-D display of all acoustic targets in the water column to several hundred meters on either side of a survey vessel. Even during the initial field trials of these tools we have been able to clearly demonstrate the value of ensonifying a large volume of water while maintaining high spatial resolution for monitoring fish behavior, fish school dynamics and vessel avoidance. The ability to isolate and analyze many, individual narrow beams presents the opportunity for new approaches to quantitative behavioral studies, biomass estimates and target identification.

LITERATURE CITED


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