The Development of the Multibeam Echosounder: A Historical Account

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Abstract: The first paper on narrow-beam echosounding was published in 1960. Since then, the advantages of the principle of multibeam swath bathymetry for seabed mapping have been recognized by many institutions working in the field of underwater area mapping. We intend to review some of the developments the multibeam echosounder has undergone in order to better understand the challenges facing the field today.

INTRODUCTION

The field of seafloor mapping has diversified into many directions since the birth of the multibeam echosounder in the 1960's. At that time most of the development was related to the mechanical and electronic system components, whereas present research focuses on widely different areas, such as more precise bottom detection algorithms, seabed classification, image processing, acoustical modelling of the backscattering process, and high-resolution methods for direction finding of plane waves. Multibeam echosounding thus encompasses many scientific disciplines. In this paper we will present some work of early times in order to understand the problems and ideas that have driven the development of swath bathymetric systems.

HISTORICAL DEVELOPMENT OF THE MULTIBEAM ECHOSOUNDER

The earliest technique of bathymetry (depth measurement in water) involved lowering a weighted-down rope or cable over the side of a ship, then measuring the length of the wet end when it reached the bottom. Inaccuracies occurred because of bending of the rope, caused by deflection from subsurface currents and ship movements. This technique was replaced in the 1920's by echo sounding, in which a sound pulse travels from the ship to the ocean floor, where it is reflected and returns. By measuring the time elapsed between pulse emission and reception, a record of seafloor topography along the ship's track can be registered.

Improvements in transducer technology and timing accuracy made possible the introduction of precision depth sounders (PDRs) in the 1950's, whose beamwidth was 30-60º, and which only made it possible to create large-scale maps of the seabed (1).

The purpose of swath bathymetry is to measure the depth at many points extending to a great distance on one or both sides of the ship, instead of measuring only directly below the ship. Swath bathymetry systems can be characterized according to the following qualitative criteria:

- Across-track coverage
- Accuracy of depth measurements
- Confidence in seabed classification method(s)
- Density of bottom sampling

The first papers on multibeam sonar appeared in the International Hydrographic Review around 1960 (2), (3). The activity in the field seems to have been rather low until the early 1980's, when computer power started to become cheaper, making feasible the use of digital processing in the systems.

Some of the developments in the early 1960's paved the way for the multibeam echosounder. One of the important results of the time is documented in (4). Single-beam depth sounding needed beam stabilization to compensate for the movements of the ship. In this article, an electronic stabilization scheme is introduced – thereby obviating the need for mechanical stabilization, and improving system reliability by getting rid of moving parts. D. G. Tucker introduces further possible improvements to single-beam systems in (5), most notably the use of interferometric techniques and electronic sector scanning of a single beam by rapidly changing the phase delay of each transducer element.

M. J. Tucker (2) provides a solution of sidelobe identification by tilting the transducer. The main lobe is stronger than the sidelobes, and when the transducer is tilted, the two first sidelobes will no longer have the same intensity, and can be distinguished in a printout. This makes it possible to obtain depth values other than just from the main lobe of the beam.

The need for area coverage instead of only covering the profile beneath the ship was partly covered by a parallel sounding method consisting of using several echo-sounders at the same time, mounted on long rods extending out from the ship (6). This was used mainly for mapping rivers, and was obviously impractical, especially in rough seas. A similar area sounding method has been implemented with towed bodies, each carrying an echosounder, and is briefly described in (7). A more advanced parallel sounding method is described in (8), where several ships navigate in parallel courses, each covering a separate area, overlapping the area covered by its neighbor ships.

One of the first articles on multibeam sonar was written by the oceanographer Morris F. Glenn in 1970 (3). Here, he describes an operational multibeam system called the Multi-Beam Array Sonar Survey System, at the time in use by the US Naval Oceanographic Office. The coverage was 90º across-track, and the system could compute up to sixty depth points per ping within this coverage. This new system greatly increased US Navy deep-ocean survey capabilities. An external gyrocompass was used for pitch compensation of the transmitted beam and electronic roll compensation of the beamforming in the receiving beams. Beamforming was done using an electronic beamforming matrix. The envelopes of the received beam signals were processed digitally, and real-time contour charts could be produced from the data.

The first multibeam echo sounder made for shallow water surveys, "Bo'sun" (naval jargon for boatswain), is presented in (9). The system formed 21 beams and had a coverage of 2.6 times water depth (105º coverage). The operating frequency was 36 kHz, and maximum survey depth was 800 m. Reference (9) describes the components of the system and evaluates the sounder, based on a test survey in the Bedford Basin. Such a system was primarily required because of the increasing number of supertankers that needed to navigate shallow channels. Pitch and roll sensors were incorporated into the system. The pitch sensor was used to steer the transmitted beam of sound to the vertical direction, while the roll sensor was used to steer the receiving beams. The construction of bottom charts had to be done off-line, because of the computation time needed. One of the most notable shortcomings of the system was the lack of computing power, and it was noted that it would be of great benefit to produce maps on board the ship.

The first multibeam echo sounder produced for deep ocean surveys - "Sea Beam" - was tested in 1977, and the first cruise is presented in (10) along with a technical description of the system. The Sea Beam had 16 beams, covering a sector of approximately 60º. The system was manufactured by GIC (General Instrument Corporation), as was its predecessor Bo'sun, constructed for use in shallower regions. The emitted pulse covered a sector 54º wide in the across-track plane, and 2.67º along-track. The receiving beams were 20º along-track and 2.67º across-track, thus intersecting the emitted beam in 16 "squares" along a strip of the bottom. A reception gate was used, which increased in size outward from the vertical beam. In (10) it is correctly predicted that: "The three-dimensional vision that [the Sea Beam system] gives of the ocean floor is such a major step forward that conventional mono-beam systems will soon become obsolete."

Another system built by GIC is the Bathymetric Swath Survey System (BS^3), which employs a vertical fan-shaped array of 21 acoustic beams forming a swath beneath the survey vessel with a width equal to 2.6 times the sounded depth. The 21 beams are obtained from two receiving arrays, each forming 11 beams, where the inner beam of each are overlapping. The operating frequency was 36 kHz, and the system was designed to operate in depths from 3 to 610 meters. Its main task was to chart harbor areas for safer passage of large ships. Reference (11) describes some of the experiences made during the first trials.

We have in the last decade witnessed advances in technology and a growing number of scientific papers on signal processing for multibeam echosounding. Unfortunately, we do not have space to cover these advances here. The reader is referred to the *IEEE Journal of Oceanic Engineering* and proceedings from the *OCEANS* conferences for further and more recent references on the subject.

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