



Multibeam Swath Bathymetry Signal Processing Techniques

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Abstract

Mathematical advances and the advances in the real time signal processing techniques in the recent times, have considerably improved the state of art in the bathymetry systems. These improvements have helped in developing high resolution swath bathymetry systems with large data handling capacity. This paper gives one such system details, the theoretical aspects and the signal processing techniques used in the HYDROSWEEP system.

Introduction

The conventional echosounders used worldwide, are able to highlight varied bottom relief with certain limitations that they can differentiate only large scale reliefs due to their broad beamwidths of the order of 30 to 60 degrees. These problems were overcome by the advent of narrow beam echosounders. Both these type of systems need several parallel sounding survey lines to create bathymetry maps. The need therefore for economising on the survey period and an advanced signal processing method to produce high resolution bathymetry maps, led to the development of multibeam swath bathymetry systems. Developments in the mathematical treatments for solving beam steering algorithms helped in building advanced electronic signal processing systems.

Multibeam Swath Bathymetry System

Multibeam Swath Bathymetry System shown in Fig. 1 is a unique type of equipment for bathymetry data acquisition, covering large areas in a short time, compared to the conventional equipment like an echosounder. HYDROSWEEP, the multibeam

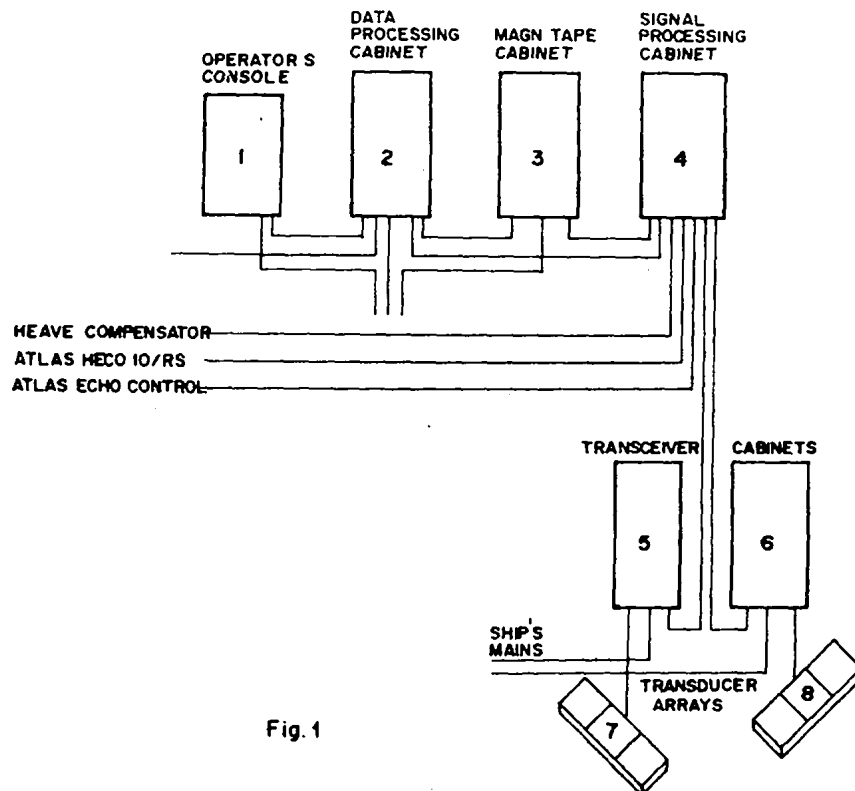


Fig. 1

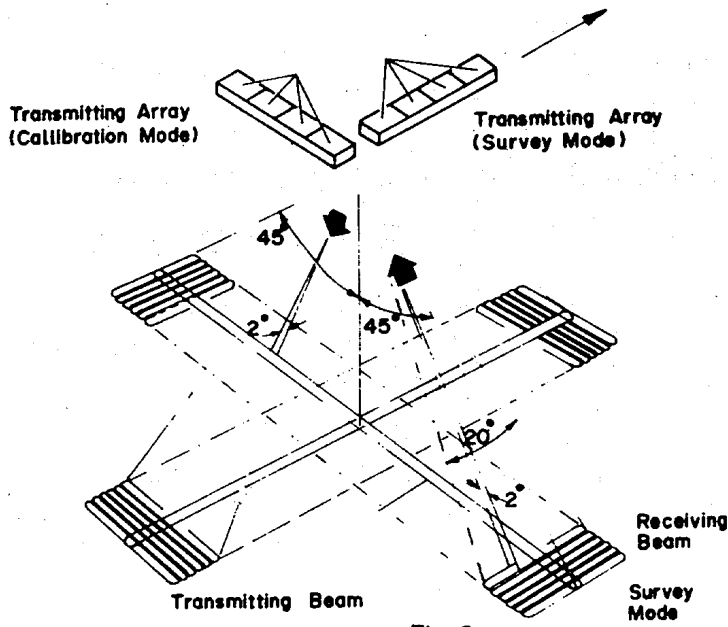


Fig. 2

swath bathymetry system, provides a swath coverage of double the water depth in transverse direction. The transmission is facilitated through two transducer arrays, one in the longitudinal direction and the second in transverse direction in a planar T configuration. The arrays can be interchanged for transmission and reception functions as they are identical. This interchanging facility is made use of for calculation of ray bending parameters, by comparing the measurements made for the centre beam in transverse mode (survey mode), with those obtained in the fore-aft mode (calibration mode), by means of interactive computation. A fairly accurate mean sound velocity through water column can be obtained by this procedure, which is used in depth calculations from outer beams (oblique angles) which are corrected for refraction effects.

Transmitted and received beams are compensated for roll, pitch and heave motions of the vessel. This electronic beam steering process ensures that the received and processed data is stabilised against any movement of the ship and is position corrected. The beam configuration of the multi narrow beam sonar is shown in Fig. 2. The signal processing unit controls the signal conditioning, beam forming and echo processing.

Signal Processing

The data obtained from a multi beam system is of a very complex nature. The beams incident obliquely on the sea floor are received in a very distorted form due to boundary reverberation problems, pulse stretching at deeper depths and the resulting phase ambiguities caused by the uneven topography. Due to larger insonification areas at deeper depths, there will be a decrease in the spatial correlation between the return signals. In order to overcome all those signal distortions, an advanced signal processing technique will have to be used, to correctly detect the bottom. Signal processing using beamforming and adaptive echo processing techniques, have been developed to tackle such complex nature problems. A brief description on the theory of beamforming applicable to multibeam sonars is given here.

As mentioned earlier the multibeam sonars are based on cross fan beams formed by the transducer arrays placed at right angles to each other. Each array is formed by multielemental pattern arranged in a linear fashion. The elements are driven in the groups of four along the column of the array, and by appropriate shading technique a proper control over the side lobes is attained. The beam pattern is given by the product of the element group pattern and the array factor. The signal processing is based on the beamforming and the echo processing of the data obtained from the preformed beams which is used for further computation of the depth data, horizontal distances and for the computation of depth contour plots. The beamforming is a process by which the amplitude and the angle of the arrival of a constant phase wavefront incident on the receiver transducer array is determined. Referring to the Fig. 3, the extra distance an incoming wavefront must travel to reach the i^{th} element after it has reached the $(n - 1)^{\text{th}}$ element, is given by $d/\lambda \sin\theta$, or, we can say that for the wavefront to reach the i^{th} element is given by [1]

$$I_n = n d/\lambda \sin\theta$$

The corresponding time delay τ_n for the distance I_n for the phase velocity of the wavefront to be c is then given by

$$\tau_n = I_n/c, \text{ where } c = f \lambda$$

where c , f and λ are sound velocity, operating frequency and the wavelength.

Corresponding phase velocity then can be given as

$$\begin{aligned}\Phi_{in} &= \omega \tau_n = 2 \pi f (l_n / c) \\ &= 2 \pi f (nd \sin\theta / c\lambda)\end{aligned}$$

In order to bring all the elements at same phase for receiving wavefront, a processing delay for the early returns will have to be supplied by the beamformer electronics. This ϕ_{pn} is given by

$$\phi_{pn} = 2 \pi (N - 1) (d/\lambda) \sin\theta_p$$

Where θ_p is the direction of steering angle and N is the number of elements or groups of elements of an array. The total phase delay will be the sum of phase delay θ_{in} and the processing delay θ_{pn} . Now, by setting the beam angle equal the steering angle the total phase delay can be made independent of the n , the element number. By this we can observe that the signal information at the input of all the elements has the same phase delay and are in phase at this point. The array pattern with N omnidirectional elements given by

$$g(\theta) = \sum_{n=0}^{N-1} A_n e^{jn\phi} \quad \text{with } \phi = 2\pi (d/\lambda) \sin\theta$$

then can be written as

$$g(\theta) = \sum_{n=0}^{N-1} A_n e^{j(\phi - \phi_n)}$$

The beam is then steered in the direction of θ . The main lobe widens as the steering angle increases from $\theta = 0^\circ$ to $\theta = 90^\circ$.

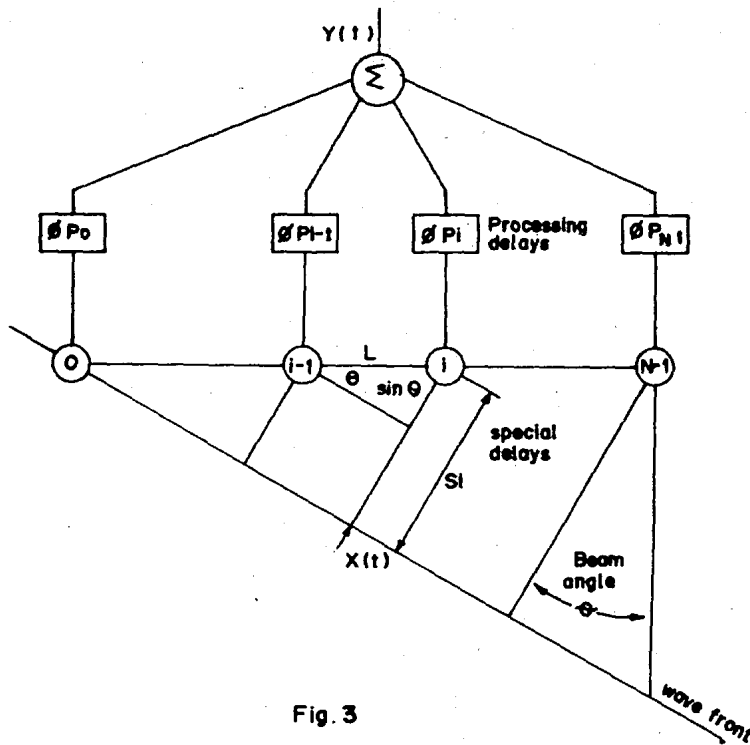


Fig. 3

A general signal flow diagram giving an idea about the signal processor components is shown in Fig. 4. In the present system the distortion correction of sound travelling time is achieved by using time multiplexing of the 72 channel data in digital format. The digital delay lines are applied in such a way that signals from desired direction are present in phase at the summation stage. By this when the signals are added, a maximum echo corresponding to a particular delay line and timing in the steered direction is obtained. The data for the addresses for steering directions are provided through the control of the processor CP-BE and the supporting circuits. The delay line data is obtained through RAMs on the address controller. By cyclic addressing of these RAMs, the incoming sampled data is stored on the delay boards. The sequence of these operations are shown in Fig. 5.

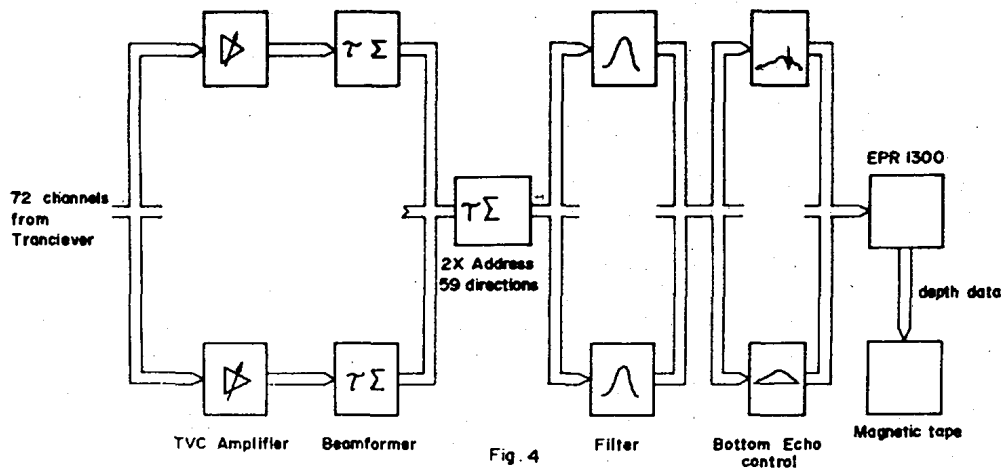


Fig. 4

The programmed delays are generated in such a way that the selected interrogation is displaced by m sampling clock pulses. Each of these τ_m thus contain number of basic delta τ . This delta τ corresponds to the write clock of the beamformer memory. This clock is selected in such a way that for each clock (sample) pulse the direction of a PFB (preformed beam) can be monitored for a change of 0.30 degrees, and for each delta τ it corresponds to a phase angle of 22.5 degrees. By generating delay information for all 72 channels a PFB with correct phase is generated to be input at the summation state. To generate all the 59 beams this process is repeated for 59 times. The data from the delay boards is summed by time multiplexing by the PFB adder stage and is provided to the PFB interface as a group of 59 beams of 8 bit information for each beam, to be serially accessed by the filtering module. The address generation for each PFB is done after compensating for the roll and pitch corrections. A memory snap shot during the application of delay lines would appear as shown in Fig. 6. As seen in this figure, there are 59×72 delay combinations available for 59 beams, to steer them in a proper direction. The data transfer rate from the beam former to filter stages is maintained at approximately 2 MHz for 72 channels to ensure proper sampling of the data.

For further signal conditioning, this data is then passed through the filter module where a narrow band filter is used to improve the signal to noise ratio. The signal is heterodyned down to 4.5 kHz using a switched capacitor filter with a variable bandwidth between 100 Hz to 2 kHz to adapt to different modes of the system operations. The data is then subject to rectification for envelope detection and is low pass filtered to A/D stages. The actual echoprocessing is carried out after this stage.

Echo Processing

The signal output at filter module stage is in a distorted form and has to be compensated for pulse stretching and scattering effects due to boundary reverberation problems for the obliquely incident beams. A window filtering technique is used by the echo processor. On recognising the presence of an echo the controller sets the window to appropriate timings in such a way that this is narrow at centre and widens for outer PFB's at a rate of $1/\cos\alpha$ where α is the steering angle. All the echo information is then sampled at 22 kHz and written into its assigned memory location. For echos coming from near vertical direction, there is a certain

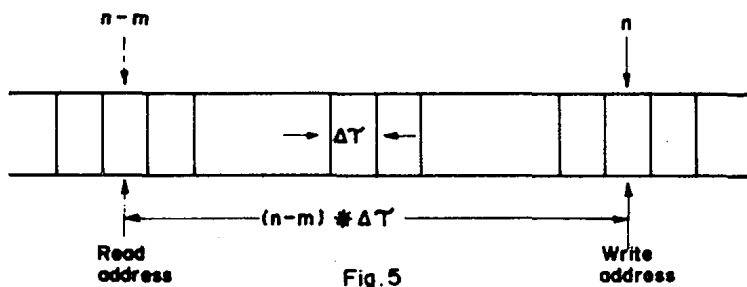


Fig. 5

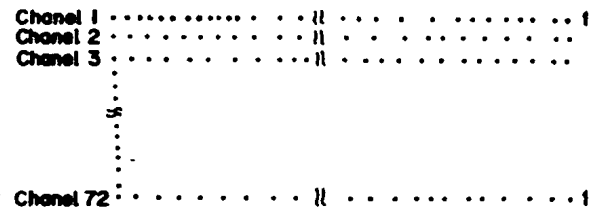


Fig. 6

resemblance with the transmit signal and the signal contents can be derived by correlation process. For the outer beams as they are stretched in time domain have phase jumps and are distorted to a maximum level. These echos have a feature, that they have a definite energy centroid of their energy distribution in space. The echo processor is designed with a special hardware and a software package which detect these energy centroids and obtain the travelling time associated with these centroids. Figure 7 gives idea of the distorted nature of echos for outer beams and the process of iterative integration process involved for energy centroid together with windowing.

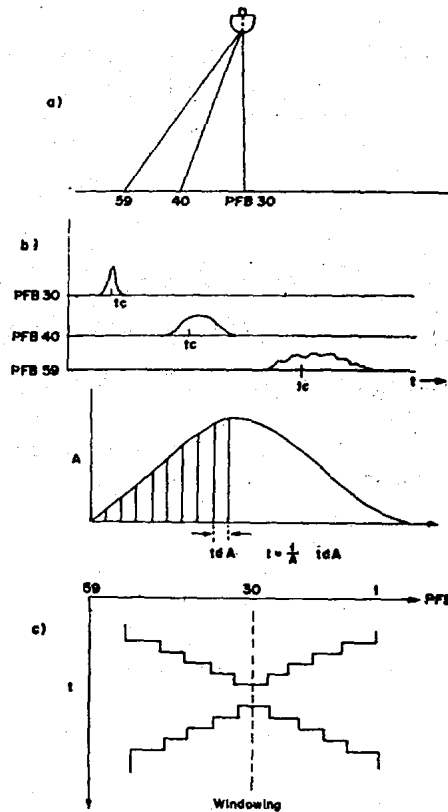


Fig. 7

For the central depth with two area energy density calculations the central beam depth can be obtained. The window time at which the energy centre is detected is termed as the pilot time. For outer beams the energy density calculations are repeated for several times to shift the window timings to newly calculated centroids. At the time when a window setting corresponds to the expected echolength, is taken for the slant length calculation.

Results

During the cruise, detail bathymetric survey of a small segment of the seafloor was carried out with multibeam hydrographic equipment. Bathymetric data along eleven N-S profiles, each of 300 nautical miles long and separated by 5 nautical miles, was collected. The area covers between latitude $9^{\circ} 45'S$ to $14^{\circ} 45'S$ and longitude $75^{\circ} 42'E$ to $76^{\circ} 38'E$.

The sea floor of the surveyed area has a number of seamounts, small ridges and swells, valleys, guyots. Larger seamounts occur mostly in the southern part of the surveyed area. The tallest seamount encountered have a height of 1170m. Two major seamounts (height $> 1000m$), ten intermediate (height = 500 - 1000m) and 9 minor seamounts (height $< 500m$) occur in the area south of the latitude $12^{\circ} 15'S$. In contrast, the northern part of the surveyed area (i.e. north $12^{\circ} 15'S$ latitude) have only minor (4 nos.) and intermediate (1 no.) seamounts. No major seamounts occurs in the northern part. However, this part shelters weak or faint traces of N-S trending parallel ridges. It appears that these ridges were lost towards south in the crumpled seafloor. Crumpling and folding of the seafloor become prominent south of the $10^{\circ}S$ latitudes. These have E-W trending axis and are arranged alternately with valleys/trenches rendering the seafloor a shape near to the highly corrugated. The height and fall of these E-W trending crumpled seafloor vary from 50m to 600m. Intense crumpling (E-W, ESE - WNW) axis trending of seafloor continues upto latitude $12^{\circ}S$. South of $12^{\circ}S$ latitude crumpling reduces, and intermediate to major seamounts start to appear.

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