Multibeam echo sounders for naval applications

An article by MARKUS SCHÄFER and CHRISTIAN ZWANZIG

Modern multibeam echo sounders provide not only bathymetric depth data, but much more information and advanced functionality. Therefore, these echo sounders can be used for a wide range of naval applications for naval surface ships and submarines. The Wärtsilä ELAC SeaBeam medium-depth multibeam echo sounder systems, operating in the 26 kHz band or 50 kHz band, provide high-resolution water column imaging (WCI) data and FM processing capabilities for increased measurement ranges and improved range resolution. Combined with high-sophisticated online visualisation and beam stacking of WCI data, automatic object detection capabilities and different transmission beam steering modes during stationary or survey operations, these multibeam systems are well-suited for several naval applications. Such applications are, for example, covert bottom mapping, bottoming procedures for submarines, submarine hunting in confined and shallow waters and submarine rescue operations of surface ships.

WCI | frequency modulation | beam stacking | object detection | submarine detection | bottom mapping

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1 Introduction

Multibeam echo sounders have a history of about fifty years: The first bathymetric sonars were developed by Harris Anti-Submarine Warfare Division of General Instruments, driven by the Cold War for charting the deep oceans for the US Naval Oceanographic Office in the 1960s. These first systems were called Swath Array Sonar Systems (SASS). The first commercial version of such a system was presented in 1976 as SeaBeam »Classic«.

In the beginning, deep water surveys were classified operations, mainly executed to support submarine operations in the oceans. Starting in the mid 1980s, multibeam echo sounders became the main sensors for hydrographic charting and research.

A multibeam echo sounder is the ideal sensor for measuring bottom topography in all areas. New developments in the last years, however, offer more applications than only receiving hydrographic information.

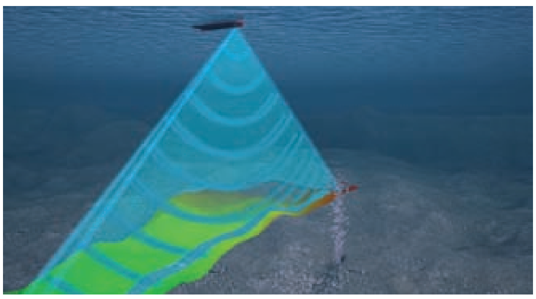

Fig. 1: Ensonified swaths of a multibeam echo sounder with dual multi-ping

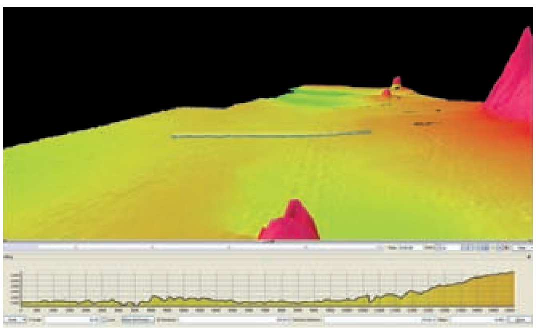

Fig. 2: Bathymetric data of an ELAC SeaBeam system

Multibeam systems generate several hundred beams with independent depth information instead of only one beam direction, measured by single-beam echo sounders.

Multibeam systems allow survey vessels to measure high-resolution depth data of the seafloor over wide swaths in far less ship time compared to single-beam echo sounders, thus greatly reducing time and costs of such mapping endeavours.

While initial multibeam echo sounders provided only a single swath per ping cycle, modern systems provide multiple swaths within one ping cycle, providing higher data density and better data quality. Fig. 1 illustrates the ensonified swaths of a multibeam echo sounder with dual multi-ping. The two swaths have different steering angles in the along-ship direction.

Multibeam echo sounders produce a huge amount of data, depending on the water depth. Normally, the data are stored on board and transferred to a post-processing station.

Still, the main application for such systems is measuring bathymetric data of the ocean floor for nautical chart production, cable laying or other offshore construction activities. Fig. 2 shows bathymetric data including a cross profile (blue line), measured by an ELAC SeaBeam system.

2 Enhanced functionality of multibeam echo sounders

Today, faster processing hardware, extensive storage capabilities and high-performance data interfaces support sophisticated data processing algorithms and the storage of huge amounts of data. Therefore, it was recently possible to implement additional and enhanced functionality into multibeam systems.

2.1 Frequency-modulated signals

While formerly only continuous wave (CW) pulses were applied, the new Mk II series of the medium-depth multibeam echo sounders ELAC SeaBeam 3050 and ELAC SeaBeam 3030 offer the possibility to apply frequency-modulated (FM) pulses for increased measurement ranges, improved range resolution and better data quality due to less signal fading.

FM pulses require a correlation of the beamformed data of all beam directions with pulse replica in order to obtain pulse compression. Additionally, Doppler shifts of the operating frequencies induced by the ship's movement have to be compensated. In order to obtain unrivalled data quality, the ELAC SeaBeam 3030 / 3050 multibeam echo sounders apply Doppler compensation not only to the bathymetric depth data, but also to the WCI data.

2.2 Water column imaging

Driven by the German research project SUGAR (Submarine Gas Hydrate Reservoirs), the ELAC WCI Viewer provides a wide and impressive functional scope for online visualisation of water column image (WCI) data:

- online and offline visualisation of high-resolution water column image (WCI) data;
- different window types for data visualisation;
- different scaling and range options;
- forward and backward data playback as movies or single pictures;
- object and event functionality;
- display of external sensor data.

These capabilities help to identify any kind of objects in the water column or on the bottom like e.g. submarines. As ELAC SeaBeam medium-depth echo sounders are successfully applied for identifying gas flares in the water column (which are indicators for submarine gas hydrates), they are as well suitable for identifying submarines.

Besides sonar data windows, showing WCI data of a single ping (see Fig. 3), the ELAC WCI Viewer includes a so-called stacked beam history window (see Fig. 4), which is excellent for identifying objects in the water column.

In the stacked beam history window, the individual pings are displayed one after the other. As a pre-step, within each ping a selectable number of across-ship beam directions are stacked on one vertical line. Fig. 4 shows stacked WCI data, acquired by an ELAC SeaBeam 3050 on the research vessel »Poseidon« in May 2014. In this window, gas flares in the water column are clearly visible (red circles).

For the beam stacking algorithm, two different modes are available:

In the so-called range stacking mode (see Fig. 5), all beam amplitudes, belonging to the same instant of time, are superimposed consecutively (i.e. range, if the water sound velocity is assumed to be constant). In this type of stacking, which is also available in some third-party post-processing packages, objects can be identified which are located in the time span of the water column before the first bottom contact. Beyond the first bottom contact, the stacked beam amplitudes are dominated by the bottom echoes.

In the so-called horizontal stacking mode (see Fig. 6), all beam amplitudes, located on horizontal lines, are superimposed. For a flat bottom, this approach utilises a wider area above the bottom for object detection. However, since the horizontal lines cross the relatively strong side lobes of the vertical bottom echo, these side lobes would mainly dominate the horizontally stacked beam amplitudes. Therefore, an algorithm for side lobe suppression is applied before the horizontal beam stacking.

2.3 Automatic object detection

Despite the ELAC WCI Viewer for the online visualisation of high-resolution WCI data, there is a

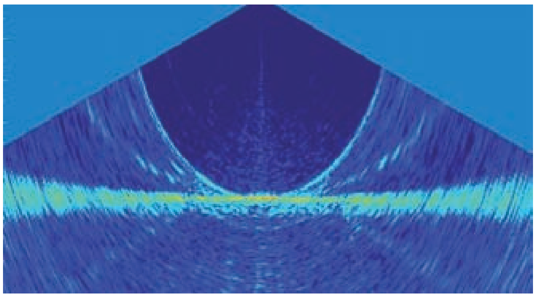

Fig. 3: Sonar data window, showing WCI data of a single ping

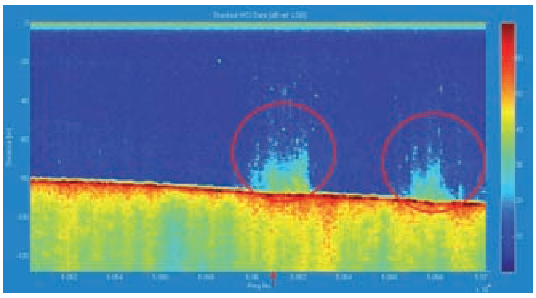

Fig. 4: Stacked beam history window with WCI data of an ELAC SeaBeam 3050

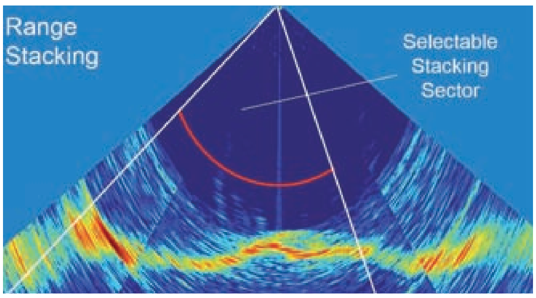

Fig. 5: Illustration of range stacking

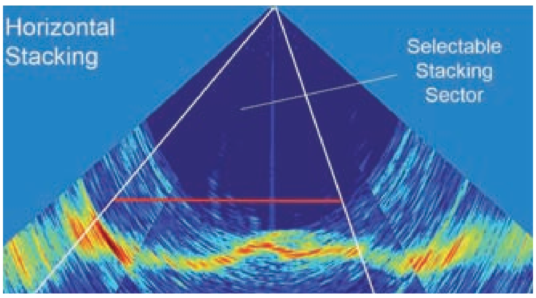

Fig. 6: Illustration of horizontal stacking

need for an automatic processing of WCI data with respect to object detection. Such automatic processing will reduce the workload of survey operators significantly.

Based upon scientific work elaborated within the SUGAR research project, Wärtsilä ELAC Nautik has developed an initial version of an Automatic Object Detector (ELAC AOD) which is currently dedicated to the automatic detection of gas flares in the water column. The ELAC AOD reads WCI data files from ELAC SeaBeam 3030 / 3050 multibeam echo sounders.

Via modification of the algorithmic configuration parameters, the ELAC AOD can be adapted to other objects like e.g. submarines.

Fig. 7 shows a sequence of consecutive pings, including a gas flare which has been automatically detected by the ELAC AOD.

2.4 Advanced transmission beam steering

The ELAC SeaBeam 3030 / 3050 multibeam echo sounders include a new functionality for the automatic cyclical steering of the transmitted swath in the along-ship direction (see Fig. 8). This functionality is particularly relevant for the analysis of objects like submarines, gas flares or leaks during stationary vessel operation or if a multibeam echo sounder is installed on a fixed platform.

The user can specify an angle range and an angular increment, resulting in a periodic oscillation of the transmitted swath to bow and to aft. Via this functionality, an entire volume area under the ship is automatically ensonified, without requiring any movement of the vessel. This feature is very helpful for submarine detection and rescue operations.

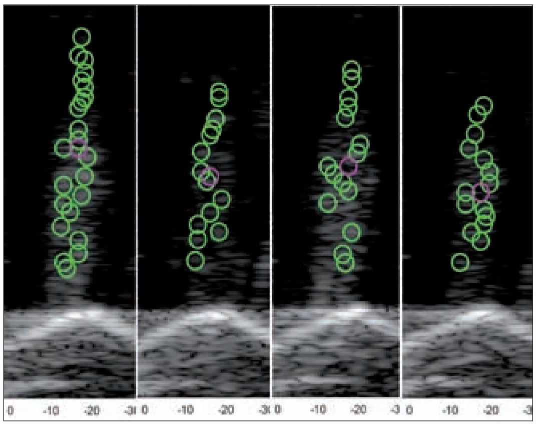

Fig. 7: Automatically detected gas flare (green: single objects within gas flare; purple: centre of gas flare)

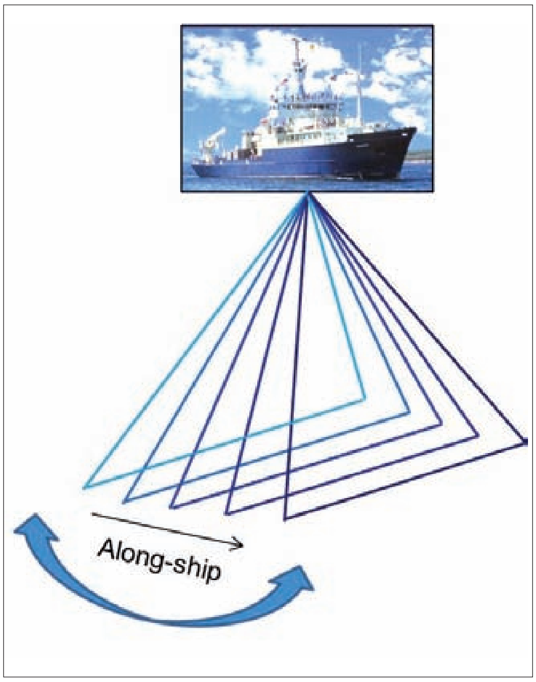

Fig. 8: Automatic cyclical steering of the transmitted swath (advanced transmission beam steering)

3 Naval applications

The above-mentioned enhanced functionality of multibeam echo sounders can be utilised for different naval applications which are described in the following.

3.1 Submarine hunting

During intelligence, surveillance and reconnaissance (ISR) missions, submarines operate in shallow waters of coastal areas for longer times.

In such regions, submarine hunting is very difficult as submarines located in the water column or lying on the bottom are difficult to detect.

The detection situation in shallow and littoral areas is characterised by a high reverberation level, which is the sum of the reverberation occurring at the sea bottom, the sea surface and by scattering layers in the ensonified water volume. Especially the sea state has a significant influence on the reverberation level.

This reverberation in combination with unwanted echoes from underwater structures interferes with the target echo of the submarine and makes detection with conventional anti-submarine warfare (ASW) sonars unlikely. Especially a stationary submarine lying on the seafloor is difficult to detect.

However, submarines lying on the bottom or hovering in the water column can be detected by means of multibeam echo sounders, providing high-resolution water column imaging (WCI) data or high-resolution side scan displays. Fig. 9 shows a series of high-resolution WCI data from the Mediterranean Sea, acquired by an ELAC SeaBeam 3050 on the research vessel »Poseidon« in May 2014.

The Automatic Object Detector (ELAC AOD) with adapted parameters for submarine detection will provide additional support to the crew.

3.2 Submarine rescue operations

For submarine rescue operations during the search and localisation phase, similar conditions as for submarine hunting are valid.

Different tools and displays can be used for online operations. Additionally to online procedures, the high-resolution data can be processed offline with post-processing tools to obtain even more detailed information to locate an object. This is more time-consuming than the online processing, but increases the potential to detect an object like a distressed submarine. Also special search patterns and procedures increase the possibility to detect such objects.

Having localised a distressed submarine, very accurate seafloor maps can be used for reliable safety planning.

Unfortunately, nautical charts are partially based on elder surveys and may not provide a highly accurate picture of the situation at the seafloor as required for rescue missions.

In order to support the navigation of submarines or to plan missions of remotely operated vehicles (ROVs) to a maximum extent, high-sophisticated 3D pictures of the seafloor can be created, based upon bathymetric data acquired by a multibeam system. Fig. 10 shows 3D bathymetric data of the Danube Delta, acquired by Geomar with an ELAC SeaBeam 3050.

The new advanced transmission beam steering functionality of the ELAC SeaBeam multibeam systems can be applied during stationary operation of the rescue ship. Without moving the ship, it allows surveying a complete area beneath the rescue ship and not only a line in the across-ship direction. This functionality can also be used during ROV operations to track the ROV in the water column, without requiring additional sonars.

3.3 Bottom mapping

The main application of multibeam echo sounders is collecting bathymetric data of the seafloor for chart production. Such data can be acquired in covert operations with a submarine, for example in hostile waters during intelligence missions.

The acquired multibeam data can also be used for bottom navigation and position fixing of a submarine during submerge navigation, comparing the currently collected data with reference data of electronic charts (see Fig. 11).

Also, for precise sonar performance prediction and mission planning in confined and shallow waters, it is necessary to have precise and up-to-date environmental data, especially the bottom topography. If only general unprecise bottom information is available, this will lead to improper sonar range predictions. A misinterpretation of the real situation could be the consequence.

3.4 Bottoming procedures

Especially in uncharted or inaccurately charted areas with a rugged topography, the risk for a submarine to get damaged during bottoming is very high. Also, objects lying on a flat and sandy bottom are difficult to detect with a conventional echo sounder, leading to an increased risk.

With the advanced transmission beam steering capability, it is possible to survey the seafloor not only directly under the transducer array, but entirely over a dedicated area below the ship. Thus, it is possible to receive detailed information on the topography of the seabed before placing the submarine on the ground. This increases the safety of the submarine especially in unknown waters.

4 Conclusion

Due to the new functionality, multibeam echo sounder systems are attractive for military customers, not only for their survey fleet but also for their operational fleet – especially for ASW surface vessels and submarines.

An automatic object detector is very useful to support the operator and to reduce the manning of the ships. Based on an automatic or manual object detection combined with the advanced transmission beam steering, a multibeam sonar could track an object and steer the swath automatically in such a manner, that the object will always be located within the ensonified volume.

Fifty years ago, the first multibeam echo sounders were developed for military applications; afterwards, they became more and more commercial. Nowadays, due to their advanced functionality, multibeam echo sounders return to naval platforms. ⚓

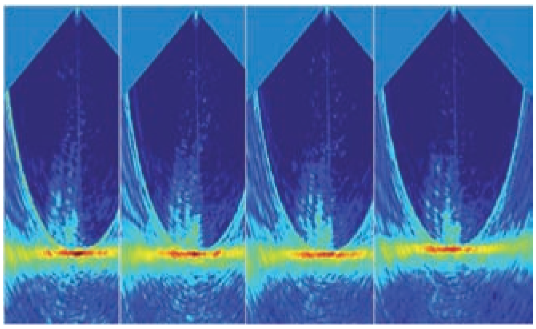

Fig. 9: Series of high-resolution WCI data

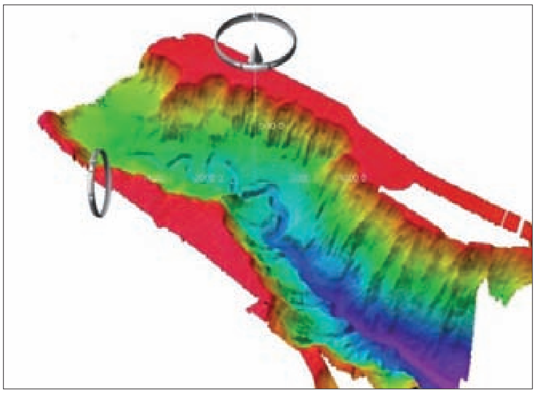

Fig. 10: 3D bathymetric data of the Danube Delta, acquired by an ELAC SeaBeam 3050

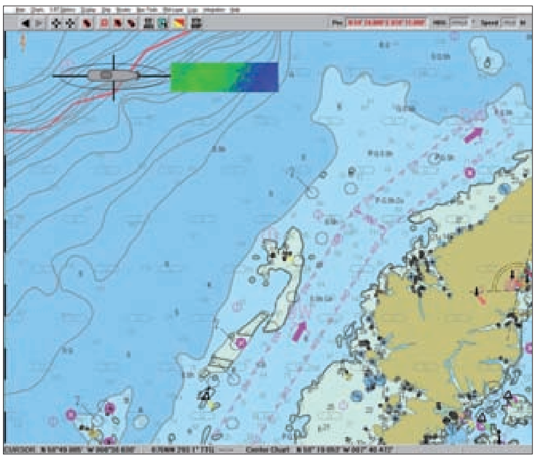

Fig. 11: Currently collected seafloor data compared to navigational chart data