Technical evaluation of side-scan sonars

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This document is an initial study comparing the performance of two commercially available U.S. side-scan sonar systems, a Marine Sonic Scout 300/900 and the 2025 Edge Tech 230/850. Both systems are designed for use with autonomous underwater vehicles (AUVs). The objective of the study was to evaluate the side-by-side performance of the two systems with the aim of identifying the system representing the best value taking into consideration both price and performance including quality of the recorded data and imaging capabilities.

Side-scan sonar | Marine Sonic Scout 300/900 | 2025 Edge Tech 230/850

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Introduction

The two side-scan sonar systems, a Marine Sonic Scout 300/900, hereinafter referred to as MST, and the 2025 Edge Tech 230/850, hereinafter referred to as ET, were installed aboard an Atlas Elektronik AUV as shown in Fig. 1. The ET transducer array was mounted in front of the MST transducer array on both sides of the vehicle. Both systems were capable of simultaneous dual- and/or single-frequency modes of operation. Both sonars were mounted with a downward looking angle of 10° (relative to the horizontal axis).

As both sonars operated in a similar frequency domain, different mission profiles were used depending on whether the sonars were operated simultaneously and separately. There was no application of acoustic management. The goal is a basic review of the performance and the quality of the recorded data and the imaging capability. Observed interferences were not a factor during the testing.

MST system

Hardware:

Marine Sonic Scout 300/900	
Frequency	300 kHz and 900 kHz dual simultaneous
Operating range (max)	300 kHz: 250 m each side 900 kHz: 80 m each side
Pulse bandwidth	300 kHz: 75 kHz 900 kHz: 200 kHz
Pulse length	300 kHz: 128 µs 900 kHz: 256 µs
Resolution across track	0.4 to 1.5 cm
Resolution along track	300 kHz: 30.5 cm @ 18.6 m range 900 kHz: 10.16 cm @ 6.2 m range
Operating depth	600 m (for the delivered transducers) Custom design up to 10,000 m
Dimensions (W × D × L)	3.81 cm × 6.35 cm × 71.12 cm (transducer)
Weight in air/saltwater	3.266 kg/1.555 kg (transducer)
Power consumption during data collection	10 W to 15 W

Software:

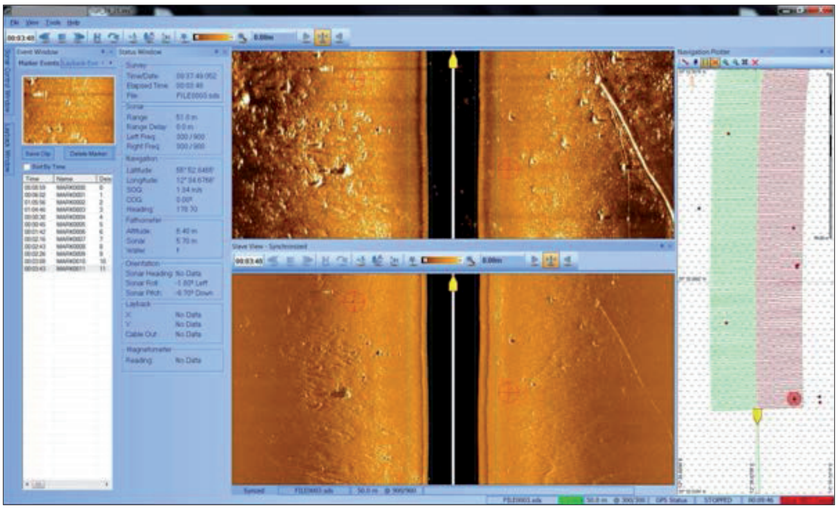
MST software provided a user interface with a wide variety of options including data replay, target marking and report generation. The system simultaneously provided both high- and low-frequency data in a waterfall display with an additional tote displaying the survey path and vehicle position (Fig. 2). Data mosaicing was not available. Replay mode operated in either forward or reverse with user defined replay speeds.

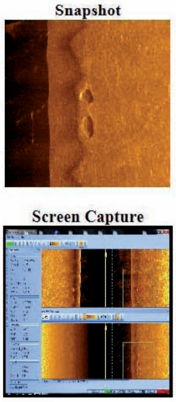
The system includes target marking a very useful feature when analysing data covering the same target during different survey lines. When the sonar-swath passed over the target, the marker reappeared and alerted the operator.

Data conversion was also included. Data was converted to the XTF format in real time without waiting for the data replay to finish. This represented considerable time savings during longer missions.

Report generation was automatic with the data provided in an HTML file that included all information for any operator marked targets including a snapshot of the target as it appeared in the high/low frequency waterfall display, the coordinates, the elapsed time and the size of the area in the snapshot. Useful for further data processing, the report also significantly reduced any need for the operator to manually record data (Fig. 3).

Fig. 1: Mounting of the sonars on the AUV





MARK0052	High Priority
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Description:	52
Latitude:	55° 52.9650' N
Longitude:	12° 34.8120' E
Elapsed Time:	00:02:20
Channel:	Starboard
Range:	15.3 m
Snapshot Height:	0.00 m
Snapshot Width:	14.47 m
COG:	0.00 deg.
SOG:	1.23 m/s
Altitude:	40.03 ft
Water Depth:	Not Available

Fig. 2 and 3: MST software main window and MST target report

ET System

Hardware:

2025 Edge Tech 230/850	
Frequency	230 kHz and 850 kHz dual simultaneous
Operating range (max)	230 kHz: 250 m each side 850 kHz: 75 m each side
Pulse bandwidth	230 kHz: 23 kHz 850 kHz: 85 kHz
Pulse length	230 kHz: uo to 8 ms 850 kHz: up to 2 ms
Resolution across track	230 kHz: 3.3 cm 850 kHz: 0.9 cm
Resolution along track	230 kHz: 1.8 m @ 200 m range 850 kHz: 10 cm @ 15 m range, 15 cm @ 40 m range and 17.5 cm @ 50 m range
Operating depth	6,000 m
Dimensions (W × D × L)	3.81 cm × 3.43 cm × 56.08 cm (transducer)
Weight in air/ saltwater	2.0 kg/1.4 kg (transducer)
Power consump-tion during data collection	15 W + 4 to 24 W

ET had a built-in processing unit that pre-processes the input time signal and calculates intensity values (thus achieving slightly higher resolution). This additional processor, however, resulted in a significantly higher power consumption rate than that of MST.

Software:
ET software provided a user interface offering limited data replay options (Fig. 4) The system simultaneously provided both high- and low-frequency data in a waterfall display. Data mosaicing was not available.

Replay mode operated only in forward, limiting the operator's ability to conduct file parsing when a specific target becomes visible in the water column.

Data conversion to an XTF format was only available in the data-replay mode at a maximum of 20 times the real time. The user was allowed to define the maximum size of the parsed XTF files, and whether or not automatic Time Varying Gain (TVG) was integrated into the data.

Testing

Both sonar systems save the raw data in a format developed or specified by the manufacturer.

MST raw data saved in a proprietary, 24-bit integer SDS format. MST played the data on-line and replayed it off-line. There was also an option to convert and save the data in XTF format. For reducing the file size the sampled data in the XTF format was compressed to 16-bit.

ET raw data saved in a producer specified, 16-bit integer JSF format. ET replay was in the off-line mode data converted to standard XTF format.

For hydrographical analysis, there are commercial software modules capable of reading the standard XTF format.

There were three different on-water survey scenarios:

- Both sonars operating simultaneously dual mode;
- MST sonar ON (while operating at a single mode), ET sonar OFF;
- ET sonar ON (while operating at a single mode), MST sonar OFF.

The surveys were conducted at two different altitudes (height over ground, HoG):

- 3 m HoG range set to 30 m for both modes;
- 5 m HoG range set to 50 m for both modes.

Scenarios were executed in the Port of Rungstedt, Denmark in November 2016. Average water depth was 14 to 17 m, and strong currents were present. There were four artificial targets: a plastic pipe, a hose, a mine-like shape and one steel/wood frame (1 m³).

In the surveyed area, there were many targets of opportunity imaged by both sonars at both frequency modes. In the first stage of the data comparison, only artificial targets were used, since their size and condition was known. In the second stage of the comparison, because of the high number, only the unknown (visible) objects were selected.

Two different approaches were used for the data analysis:

- Data analysis based on sonar images using standard hydrographic software.
- MATLAB based quantitative data analysis conducted on the raw (amplitude) data.

During each mission, the area of interest was surveyed twice; once north-south, and once south-north. For the analysis, only north-south tracks were used as current effects on the AUV's motion in the opposite direction were significant.

Data processing was done via Teledyne's Caris SIPS 9.1.9 and 10.1. The ET JSF data was imported directly into the processing software. Since the SDS format of MST data could not be imported directly, MST system software was converted into XTF before being imported.

Image-based data analysis

For the analyses, different mosaics were created. In general, the mosaics represent the sonar data resolution on the seabed. For each analysis, the local across- and along-track resolution was determined. The across-track resolution was assessed by number of intensity values in across-track direction and the range. The along-track resolution was determined based on the time between consecutive pings and speed of the survey platform. These values were taken from the corresponding track and ping statistics in the processing software. As chosen mosaic resolution corresponds to the highest resolution occurring in the data sets, the data is not artificially down-sampled and the consistent resolution of the different mosaics ensures comparability.

During mosaicking, no corrections were applied to the intensities to avoid changes to the intensity values which might result in different effects for both investigated sonar data sets and therefore would have an influence on the comparison results.

For the analysis mosaics of the targets were created. For each mosaic the mean, median, max value, min value and dynamic range were calculated. Different analysis based on the mosaics was done for the sonar comparison:

Statistical analysis: The comparison of statistical properties of mosaics including targets provides information about the influence of the presence of targets for the specific set up and can be compared between the different sonars and frequencies.

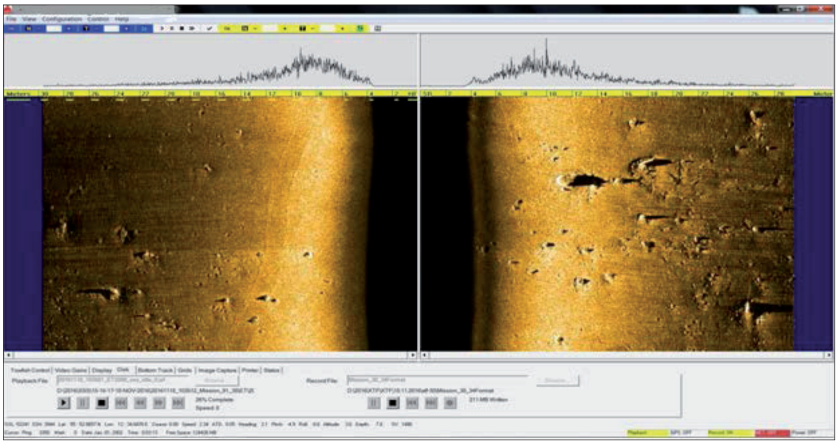

Fig. 4: ET software main window

Visualisation: For a visual comparison of the target mosaics the colour scales were adjusted to the dynamic range of the respective data set. Two scales were used: 10 colour, a discrete scale divided into ten equal intervals, and greyscale, a continuous scale ranging from black (min intensity) to white (max intensity). For increasing the visibility of the lower intensity values, the maximum range was set to one third of the dynamic range (Fig. 5).

Histograms depict the number of present intensity values within a mosaic and their distribution. A set of results from one of the missions is shown in the table below. The results are of the hose target recorded on the port side at a distance of 25 to 40 m from the track line when travelling north-south.

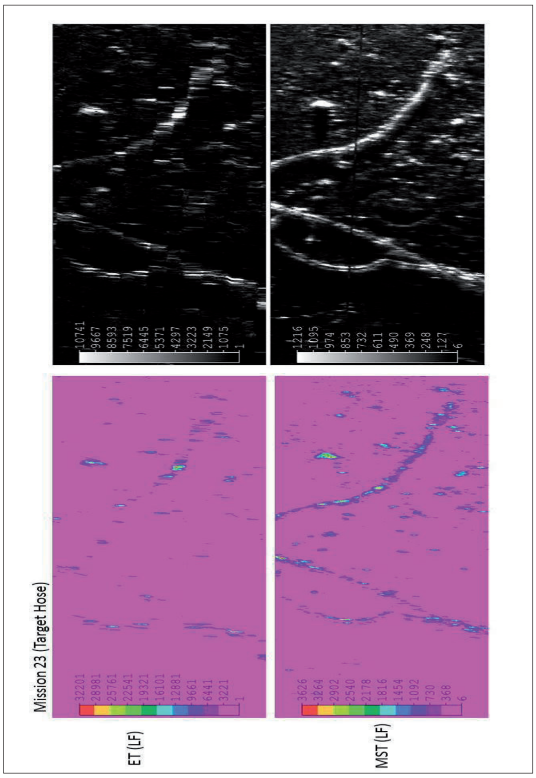

Fig. 5: Visualisation of the target mosaics

Sonar	Dynamic range	Min		25 % quantile		Median		75 % quantile		Max		Mean	
		Orig.	Norm.	Orig.	Norm.	Orig.	Norm.	Orig.	Norm.	Orig.	Norm.	Orig.	Norm.
ET (LF)	32195.90	1.1	0.0	274.4	0.8	457.7	1.4	801.9	2.5	32197.0	100.0	789.3	2.4
MST (LF)	3606.10	5.8	0.0	47.3	1.2	98.6	2.6	188.8	5.1	3611.0	100.0	166.1	4.4

Table: Statistical values for the mosaics created of the data in the area of the hose

Amplitude-based quantitative analysis

For quantitative analysis, a set of post processing methods was used. Amplitudes (their absolute values, without any kind of normalisation) were imported directly into MATLAB.

First step: Targets appearing on both sonars and distinctly positioned without overlap or interference were selected for closer analysis. The same targets were selected for both data sets.

Second step: In the region of each target two main values were manually selected: Maximum highlight (maximum backscatter), Minimum of shadow.

Additionally, an along-swath mean was calculated through all the pings in the data matrix and used for evaluation. Providing values for the ›background‹ amplitude.

Third step: In MATLAB, a region is defined with 20 cm × 20 cm window around the objects centre. For example: during the low-frequency mode at 50 m range and at 9.6 cm along-track resolution: for MST this window corresponded to 7 × 2 sample points (swath resolution 2.7 cm), and for ET this window corresponded to 10 × 2 points (swath resolution 1.9 cm). The window size is calculated according to the resolution along the swath line (which differs for both sonars and for both frequency modes). The selection of a specific window is based on the fact that the majority of selected objects fell within that size. Additionally, in these regions the mean at the highlight area (maximum) and the mean at the shadow area (minimum) are calculated. For each target the following was calculated: Max highlight, Max shadow, Contrast.

For the comparison purpose the differences of these values were calculated (for the same targets viewed at both sonars): Max differences, Min differences, Contrast differences.

Background level was calculated as mean through five points from the mean of all values along the pings. In each of five missions, objects on the seafloor in the images were chosen and their highlight, shadow and contrast values calculated and recorded. In general, a sonar performance is good if the values of the highlights (relative to background) are high; if the values of the shadows (relative to background) are low; and if the overall contrast is high.

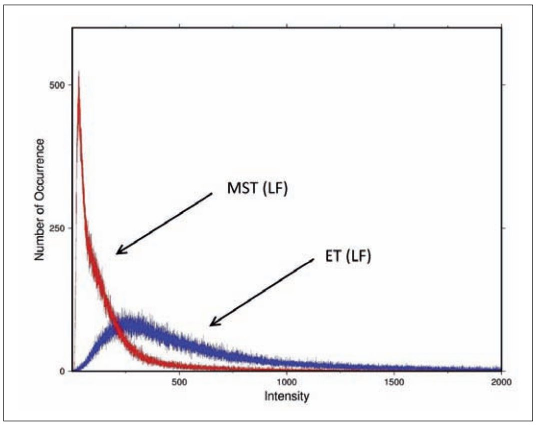

Fig. 6: Target histograms (hose)

Imaging results

Eight comparisons based on mosaics of three targets and one larger area were done. For each comparison, a mosaic was generated matching the extent of the target and adjusted to the lowest resolution of samples present. Properties of dynamic range, minimum, 25 %-quantile, median, mean, 75 %-quantile, and maximum were computed for each mosaic. These parameters were also normalised regarding the dynamic range for a relative comparison and visualised within boxplots.

The extent of the mosaics was adjusted to the extent of the targets. Targets cause high-intensity values as the acoustic signal is directly reflected to the sonar. Depending on the shape of the target a corresponding shadow area with very low intensities accompanies the highlight created by the target.

For all analysed mosaics, the dynamic range of the ET data was higher (9 to 58 times) than of the MST data. However, when examining the general relative intensity distribution the majority (75 %) of intensities were found in the lower part (0.2 to 12 %) of the dynamic range. For both sonars, the difference between the median intensity value and the target induced maximum intensity is very large as the 75 %-quantile was not exceeding 4.3 % for ET (LF, mission 31 – mine dummy) and 12.6 % for MST (LF, mission 28 – frame target). In comparison, the 75 %-quantile was generally higher for MST (by factor 2 to 14) than for ET.

As ET shows a large dynamic range, it can be concluded that the difference in intensities of the highlight, seabed and target is larger than for MST. For a quantitative target detection, such significant difference would be of advantage. This is also visible when comparing the mosaics of the targets where the colour scale was adjusted to the dynamic range. In the ET mosaics the highlights are emphasised, as the difference in intensity of the targets and the surrounding is larger than for MST.

Accordingly, more details of the surrounding seabed are visible in the MST mosaics. Not only the highlights are therefore visible, but also the surrounding seabed. In comparison for the mosaics of the full tracks the colour scale was adjusted according to the 75 %-quantile. Hence the highlight is not that strongly emphasised, but one gets a better impression of the surrounding seabed and the shadow created by the target.

The difference of the absolute minima of the intensity ranges for both sonars is insignificantly small as the largest minima vary between zero and 28. However, the difference of the maxima of the intensity range for both sonars varies strongly. When examining the histograms (depicting the lower part of the absolute intensities) in Fig. 6 the accumulation of intensity values in the lower part of the range can be observed. This accounts for both investigated sonars. The curves have similar shapes, in general, but it can be noticed that a kind of scaling factor is present. The same image information is given within a narrower range of intensities for MST.

As a result of the narrower distribution of the majority of intensity values, neighbouring mosaic cells representing the same surface have a smaller quantitative difference in intensities than a data set with a broader distribution. The noise visible in a mosaic of a larger area of the seabed would therefore be smaller in the narrower distribution of absolute intensity values as the MST data set.

Summary of amplitude-based analysis

Five missions were conducted with 36 and 47 objects being considered for quantitative analysis.

Mission 23, both sonars operating simultaneously in low-frequency mode over 47 selected objects. MST showed better object distinction (contrast level) in 83 % of the highlights, 98 % of the shadows and 95.7 % of the overall contrast.

Missions 28 and 31, both sonars operating separately in low-frequency mode over 36 selected objects. MST showed better object distinction in 61 % for highlight, in 100 % of the shadows and with 86 % better contrast.

Missions 29 and 30, both sonars operating separately in high-frequency mode over 36 selected objects. MST showed better object distinction in 78.7 % for highlight, in 95.7 % of the shadows and with 93.6 % better contrast.

According to the analysis in all cases, MST displayed better performance regarding object distinction (highlight, shadow and contrast). The quantitative differences of neighbouring intensities within an area representing the same feature (seabed or target) are smaller. Therefore, the local intensity distribution is more homogeneous and the identification of objects is better.

Conclusion

In conclusion, it can be stated that the larger difference between the general intensities (seabed) and the high intensities (target) for ET results in a clearer accentuation of objects within the mosaics. However, MST makes more efficient use of the dynamic range. The narrower distribution of the general intensity values results in a more homogeneous, and less noise affected image of a specific area (seabed, target). The identification of areas representing seabed or a target is therefore better for MST.

When using side-scan sonar for AUVs several factors need to be considered: the size of the entire system, the use of the software for displaying and editing the data, the quality of the recorded signals, the energy consumption and cost. Based upon these factors MST displayed significant advantages. ⚓