MBES DATA SIMULATION: ASSESSMENT BY DIRECT COMPARISON WITH A HIGH-RESOLUTION MULTI-SETTINGS WRECK SURVEY.

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Abstract: *Simulation is a valuable tool when developing new sonar designs or survey strategies. By avoiding expensive and time-consuming sea trials, simulations can help to test and identify the optimum acquisition settings, especially when dealing with complex bathymetry. In this contribution, a simulator output consisting of synthetic Multi-Beam Echo-Sounder (MBES) water-column data is compared against high-resolution real data. The simulator allows the user to specify array geometry, pulse type and a point-based seabed model. In 2015, a 92 meters WWI wreck (SS Polwell) located in the Irish Sea was mapped using various multibeam acquisition settings, including multiple frequencies, modes, pulse rates, angular sectors, beam spacing, bandwidth and bottom detection modes. The survey configurations have been replicated in the simulator. We provide a ready to use framework for generating the data. The array imitates a Kongsberg EM-2040 and the scenario encapsulates the effects of key acquisition settings. The input model is an ultra-dense point cloud of the wreck created from a combination of all MBES data acquired in 2015. Moreover, the signal processing is designed to match the embedded system. Examples of synthetic water-column images are presented and compared with the original survey measurements. Finally, system-specific artifacts such as sidelobes are examined in more detail. Based on the outcome of the modelling experiment, this simulator can be used to advise hydrographers and researchers on the optimum survey strategy to image objects exposed on the seabed.*
Keywords: *Simulation, Sonar, Ultrasound, Multi-beam echo sounder, shipwreck, INFOMAR.*

1. MBES DATA SIMULATOR:

Sonar data simulation is a valuable asset for acoustic engineers and hydrographic surveyors. Firstly, it reduces time, cost and uncertainty when developing a new sonar system. Secondly it helps to validate the optimum system settings and survey strategy before a specific mission. In a previous contribution [1], we introduced a simulator which is able to generate sonar data at various processing stages. The program uses the ultrasound package Field II [2], [3] to model the wave-field radiated by any array design with arbitrary geometry and pulse shape. The scene is modelled as an extended scatterer target [4]. Finally, it integrates reliable Multi-Beam Echo Sounder (MBES) signal processing algorithms [5]. For a more complete description of the simulator, the reader is invited to read [1].

Sidelobes and thermal noise levels are determined by the characteristics of the sonar array. Therefore, it is necessary to verify that these features are contained in the synthetic water column images.

In this contribution we assess the quality of the simulated data by comparing them with real survey data. A very dense multi-setting wreck (*SS Polwell*) point cloud is used to generate the extended scatterer input model. Then we compare the nature of water-column data generated with different sonar settings. Finally, we compare the accuracy of the bottom detection algorithms.

2. POLWELL DATASET

The real MBES dataset used, was acquired over a WWI metal wreck (*SS Polwell*) located on a 30m deep sandy seabed in the Irish Sea. The ship is 92m long and has a maximum width of 12m. The original purpose of the *Polwell* survey was to investigate the effect of acquisition settings and survey design strategies for optimal imaging of wrecks. The mapping process has been repeated several times (84 passes) with various aspect angles and sonar settings. It includes multiple frequencies, pulse length, swath width and bottom detection algorithms. Detailed information about the *Polwell* survey is available in [6].

Multibeam data were acquired using Kongsberg Maritime Seafloor Information System and standard multibeam acquisition procedures were followed. data were imported and edited in Caris HIPS & SIPS v9.0 hydrographic package [7]. Combinations of automated and manual processing procedures were applied to carefully preserve the ship structure. Finally, an ultra-dense point-cloud was produced combining all cleaned soundings falling within an uncertainty of IHO Order 1a [8] (Fig. 1 left).

3. SIMULATION SETUP

The simulation setup was designed to reproduce the real measurements and emulate the effect of the MBES acquisition settings. We generated synthetic data from two specific swaths. Their locations are presented in Fig. 1 and match the georeferenced positions of the Research Vessel in the *Polwell* survey.

At the first location (Site A), the transmit mainlobe penetrated between the broken wreck structure while the transmit sidelobes illuminated the deck and a part of the internal ship structure. At the second site (Site B), the sonar is located near the stern, 10m away from the deck. In this example the transmit mainlobe illuminated the wreck deck and the mast. The starboard part of the hull and a portion of the seabed were hidden by the shadow of the wreck.

The simulated array geometry was a Mill’s cross array similar to a Kongsberg EM2040 used on the research vessel [9]. Table 1 describes the various sonar settings used in the three different simulation scenarios. The point-cloud density provided a significant number of scatters per resolution cell. The amplitude of each point was modelled as a random gaussian variable. For simplicity, the acoustic shadow was simulated by removing the scatterers not located in the sonar line of sight. Such process can be automated using terrain analysis algorithms (e.g. viewshed [10])

The signal processing, from raw channels data to depth sounding, was performed is the time domain [11]. White Gaussian Noise (WGN) uncorrelated between channels was added on the Rx channels to simulate the effect of thermal noise. Raw channel data were bandpassed and matched-filtered [4]. Water-column image generation was done with the ultrasound processing toolbox USTB [5]. Dynamic focusing beamforming was performed in the nearfield. Dolph–Chebyshev windows were designed to keep the transmit and receive sidelobe level at -40dB. Finally, bottom depth was estimated with the centre of gravity method [11], [12]. The estimation was obtained from the weighted sum of the signal amplitude 10 dB under the maximum value. We expect slightly reduced performance compared to the internal EM2040 bottom detector algorithm which relies on multiple detection methods [11]. Nevertheless, the method provides a satisfactory level of accuracy for the scope of this study.

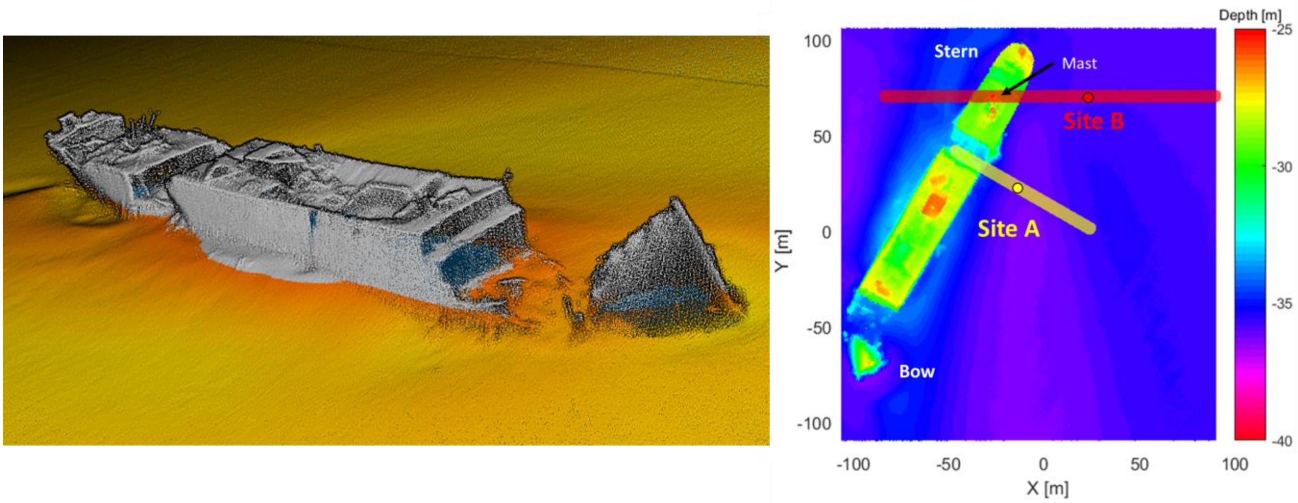

Fig.1: Left: Point Cloud generated from the multi-settings survey data.

Right: Location of the simulated scenarios. Colour overlay indicates the transmit mainlobe footprint. Circular markers indicate the sonar position at the surface.

Scenarios / **Parameters**	*1*	*2*	*3*
Site location	A	A	B
Nominal frequency	200 kHz	400 kHz	400 kHz
Swath opening angle	60 deg	60 deg	110 deg
Rx resolution	1.5 deg	0.7 deg	0.7 deg
Tx resolution	1.5 deg	0.7 deg	0.7 deg
Pulse resolution	52.5mm	37.5mm	37.5mm
Pulse length	70µs	50 µs	50 µs

Table 1: Key parameters used to emulate the real data.

4. RESULTS

We compare real and simulated water-column images and consider the performance of the bottom detection algorithms. Fig. 2 and Fig. 3 show the beamformed images of scenarios 1 and 2. The spatial location and energy content of the sonar mainlobe is comparable between real and synthetic data. Increasing the nominal frequency provides the expected angular resolution gain. Moreover, the scenarios successfully captured the undesired inherent characteristic of the MBES array: the transmit sidelobe generates a ghost image of the wreck deck and its internal structure 5m above the seafloor. The echo is visible at -40dB under the peak amplitude value. Furthermore, the nadir specular reflection induces a strong receive sidelobe located in the water-column at a constant radius.

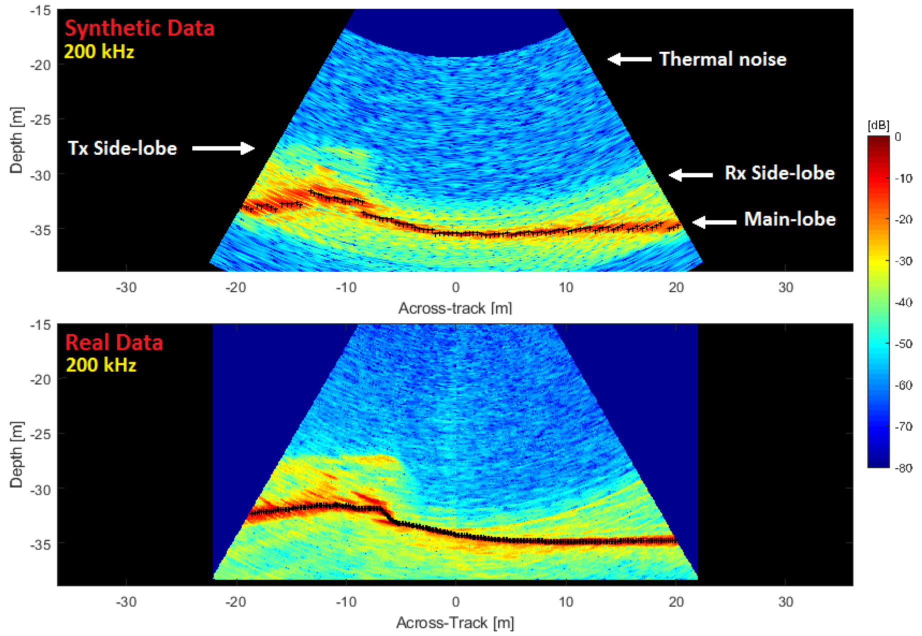

Fig. 2: Scenario 1: Upper: simulated water-column data. Lower: Real water-column data. The black markers "+" indicates the detected sea bottom.

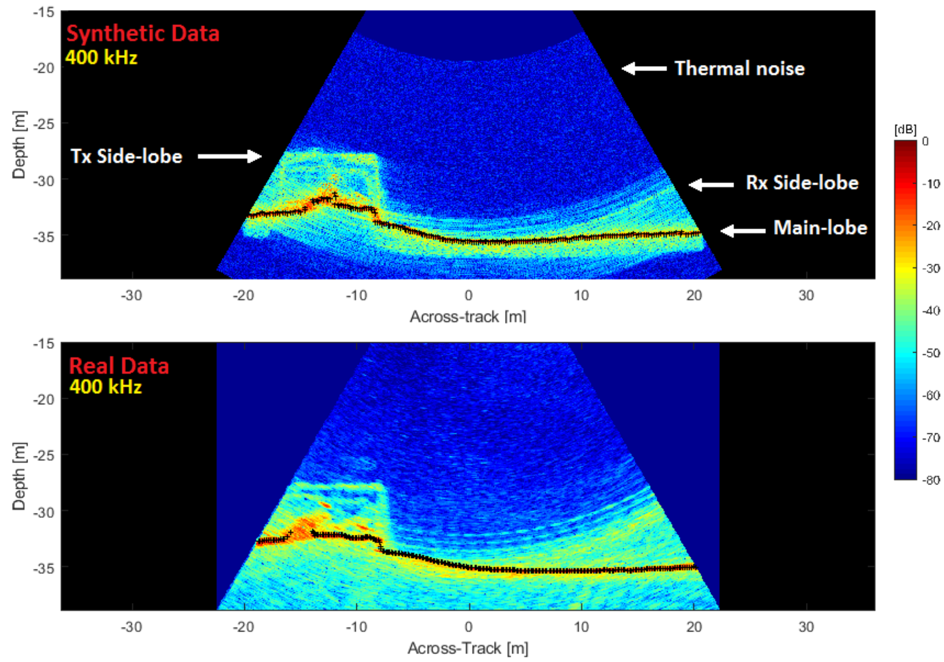

Fig. 3: Scenario2: Upper: simulated water-column data. Lower: Real water-column data. The black markers "+" indicates the detected sea bottom.

Fig. 4 shows the water-column images obtained in scenario 3. As observed in the previous example, the location and energy content of the sonar mainlobe is correctly emulated. The narrow angular resolution provided by the 400 kHz mode managed to image and detect the strong scatterer that coincide with the mast location. Acoustic shadow was generated by discarding the scatterers not located in the sonar line of sight. This solution provided satisfactory results since the aspect of shadow on the hull and the seabed appeared to be reproduced.

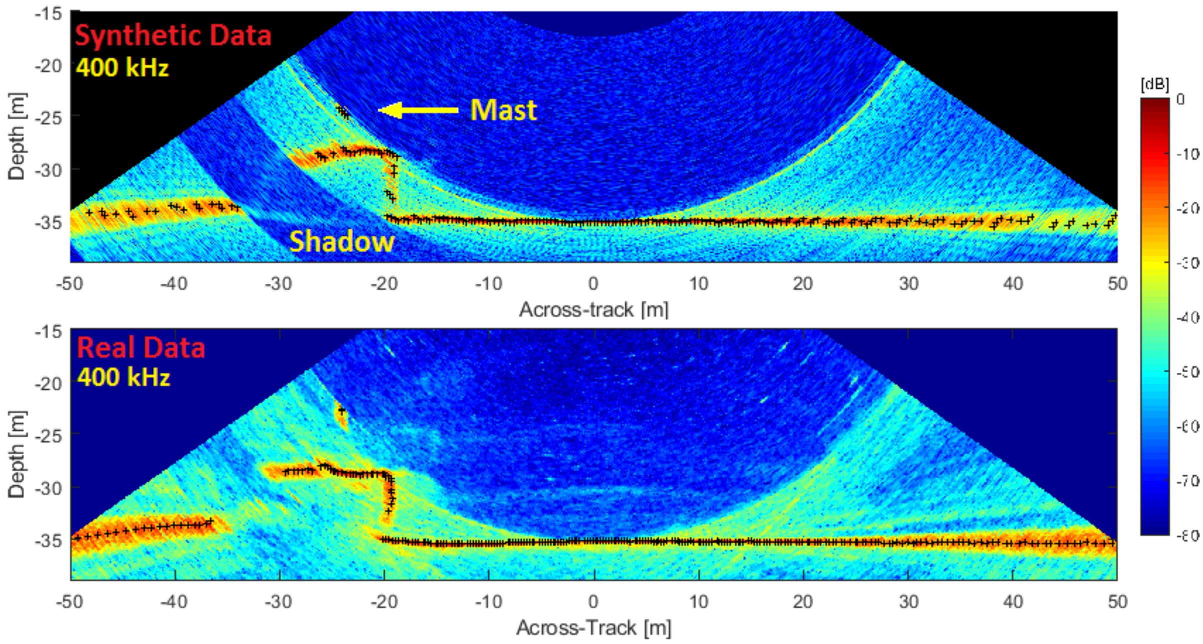

Fig. 4: Scenario3: Upper: simulated water-column data. Lower: Real water-column data. The black markers "+" indicates the detected sea bottom.

Finally, a comparison of bottom detection results is shown in Fig. 5. For the real data the depth was estimated with the "minimum depth" detection mode [13]. This mode solves ambiguous multi-detections by selecting the echo with the shallowest depth. The simulation used only the centre of gravity detector for simplicity. In all cases, the 200 kHz mode identified the ship structure with a reduced accuracy. As expected, the centre of gravity method produced less accurate results on the wreck structure and for steering angles beyond 25 degrees. A depth difference of 0.5 m, starting at 7m across track from nadir is visible in scenarios 1 and 2 on Fig. 5. We interpret this as an effect of an imperfect orientation of the mainlobe corridor in the simulation. The detection performance of the internal EM2040 bottom detector is interpreted as an effect of its possible advanced complexity: multiple-detection methods (leading edge, centre of gravity and phase difference) [9] and additional post-processing techniques (smoothing and cleaning) produced a more precise depth sounding.

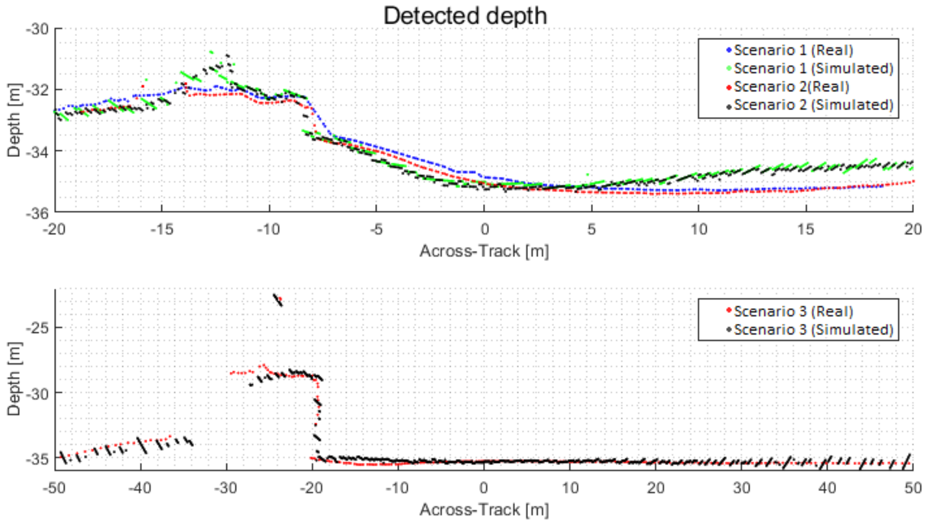

Fig. 5: Estimated depth after bottom detection. For real data the depth was estimated via the constructor bottom detector with minimum depth mode.

5. DISCUSSION

The current study demonstrates the possibility to generate MBES water-column data and detection for a specific choice of sonar parameters. In addition to this work, motion induced perturbation such as Doppler can be simulated.
We consider two main applications: Firstly, this tool offers to acoustical engineers the possibility to experiment easily with new system design such as antenna geometry and pulse type. A simulator provides by definition the real ground-truthing. It offers to compare accurately various signal processing algorithms and tailor the processing chain for a given application. The second application is geared towards hydrographic surveyors and researchers desiring to benchmark and optimize the survey and acquisition settings prior to a survey. This work demonstrated that a point cloud or a digital terrain model populated with scatterers was sufficient for simulating water-column data.
Finally, this simulation tool can be used for training of humans or algorithms to various tasks such as interpretation and processing of MBES data.

6. CONCLUSION

We studied the possibility to emulate MBES data at various processing stages. The comparison was done against a high-quality multi-settings MBES wreck dataset. The study has considered the effect of acquisition settings on the characteristics of water-column images. We provided a large body of examples representative of the features encountered in wreck surveying missions. Results demonstrated a satisfying match between real and synthetic data. The structure of water-column data was reproduced with system specific artefacts while the bottom detection identified the ship framework with a similar level of details.

7. DOWNLOADABLE RESOURCES

The simulator and a simple MATLAB tutorial can be downloaded at the address:
http://www.ustb.no/publications/multibeam-sonar-simulation/
Please refer to [1] and this paper if you decide to use the simulator for any academic purpose.
The ultrasound simulator field-II can be downloaded at: http://field-ii.dk//.

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