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DVocean Digital

A simulation prototype for hydrographic 3D measurements using multibeam echo sounder

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The (practical) training of hydrography students in the Master's degree programme in Geodesy and Geoinformatics is an important and challenging task for HafenCity University (HCU) Hamburg, as graduates will continue to be urgently needed for surveying the world's oceans and inland waters in the future. Since the ship capacities for students training in hydrography in the Geodesy and Geoinformatics study programme are limited in terms of time and space, an interactive 3D application was developed to simulate hydrographic measurements in the Port of Hamburg. This article describes the development of the application for the simulation of hydrographic 3D measurements using a multibeam echo sounder (MBES) in combination with GNSS/IMU positioning sensors integrated in the virtual 3D model of the surveying vessel *DVocean* of HCU Hamburg.

3D | hydrography | knowledge transfer | QGIS | simulation | Unreal Engine
3D | Hydrographie | Wissenstransfer | QGIS | Simulation | Unreal Engine

Die (praxisnahe) Ausbildung der Hydrographie-Studierenden im Masterstudiengang Geodäsie und Geoinformatik ist für die HafenCity Universität (HCU) Hamburg eine wichtige und herausfordernde Aufgabe, da die Absolventen auch in Zukunft dringend für die Vermessung der Weltmeere und Binnengewässer benötigt werden. Da die Schiffskapazitäten für die Hydrographieausbildung der Studierenden im Studiengang Geodäsie und Geoinformatik zeitlich und räumlich begrenzt sind, wurde eine interaktive 3D-Anwendung entwickelt, die hydrographische Messungen im Hamburger Hafen simuliert. Dieser Artikel beschreibt die Entwicklung einer Applikation zur Simulation von hydrographischen 3D-Messungen mit einem Fächerecholot (MBES) in Kombination mit GNSS/IMU-Positionierungssensoren, die in das virtuelle 3D-Modell des Vermessungsschiffes *DVocean* der HCU Hamburg integriert sind.

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1 Introduction

Maritime shipping is of great importance to the Port of Hamburg as an economic factor. Therefore, the safety of maritime navigation is an important prerequisite for ensuring the smooth exchange of goods in the port. Safe shipping routes are achieved through permanent surveying of the shipping channels, river environment and seas, where up-to-date maritime charts are continuously produced. The production of up-to-date and precise maps requires modern equipment (ships and corresponding sensors) and trained personnel. In the hydrography specialisation of the Master's degree programme in Geodesy and Geoinformatics at HafenCity University (HCU) Hamburg, hydrographic students are trained according to the standard of the IHO (International Hydrographic Organization). For this purpose, HCU Hamburg also employs its own survey ship, the *DVocean*, which, however, due to its size can accommodate only six students on the ship at the same time. With approximately 30 hydrography

students per year in the Master's programme, this means that only a limited capacity of ship time is available for practical training on the water. Hence, the training and educational skills expected today from hydrographic engineers surpass their ability to follow them consistently during the study due to this limited ship capacity.

Consequently, the development of an application for the simulation of surveying trips with the corresponding sensor technology in the Port of Hamburg and on the river Elbe represents an interesting alternative on the one hand and a sensible and important supplement for practical education and training on the other. The aim of the project was to develop an interactive application using a suitable programming environment (e.g. the game engine Unreal). This app is then used not only to control the ship, but the special focus is on controlling and simulating the data acquisition of the positioning sensors (GNSS and inertial system) and the recording sensors (e.g. multibeam echo sounder for the first app version). The simu-

lated recordings of the survey drives generate corresponding synthetic data that can be used for the subsequent evaluation processes in the further course of the training. An important aspect in the control of the respective sensor technology is the use of the corresponding software interfaces (menus) in the simulation with the integration of help functions and learning videos (tutorials).

After a brief summary of related work in section 2, the surveying vessel *DVocean* is described in section 3, while the concept and the related environment for data acquisition are introduced in section 4. The main part of this article is the description of the generation of the 3D model, the programming workflow and the introduction of functionality (section 5). The results and an example analysis are presented in section 6, followed by conclusions and outlook in section 7.

2 Related works

Historical ships have already been reconstructed as 3D models and used in applications for the purpose of knowledge transfer as demonstrated for the four-masted barque *Peking* (Kersten et al. 2020) and for the representative 3D models of four significant historic warships (the British *Asia*, the French frigate *Armide*, the Russian *Azov* and the Ottoman *Kuh-I-Revan*) that participated in the battle of Navarino in 1827 at the south-west coast of the Peloponnese (Liaskos et al. 2022). Terrestrial laser scanning was already used for the determination of sensor position on a ship and in combination with Structure-from-Motion (SfM) photogrammetry for reconstructing a 3D ship model (Wujanz et al. 2013).

Simulation programmes are available across various disciplines. However, the focus for these simulations programmes is not on sensors for (hydrographic) 3D measurements, but on ship navigation. Xue et al. (2011) present an automatic simulation programme of ship navigation for finding safe passage for ships in possible collision situations using an effective and practical method with no or minimum intervention of a human navigator. Early developments in ship simulation using even virtual reality technique are described by Xiufeng et al. (2004) and Cao (2016). Recently, some authors present an entire ship simulation training platform based on virtual reality (Yin et al. 2021), a training in ship navigation using virtual reality (Lvov and Popova 2019) and augmented reality (Templin et al. 2022) to support safe navigation, and the technology ShipSEVR (Ship Safety Education with Virtual Reality) to optimise the impact in ship and maritime safety (Markopoulos et al. 2020).

However, the goal of this project is not the simulation of ship navigation, but to control and simulate the data acquisition using different sensors, i.e. the measurements of the positioning sensors

(GNSS and inertial system) and the recording sensors (here MBES). In a similar project, a terrestrial laser scanner simulator has been developed by Luhmann et al. (2022) as educational tool for learning and teaching laser scanning processes. Apart from this software, so far other simulation software for geodetic instruments is not available in the literature.

3 The surveying vessel *DVocean*

The *DVocean* is HCU's new surveying vessel, designed for use in both research projects and teaching. The aluminium vessel (Table 1) measures approximately 8 m in length and 2.6 m in width. Thus, it can be easily transported by a trailer to more distant measuring areas. In addition to the skipper, the cabin provides sufficient working space for six people. The boat has been optimised for use in shallow water. The *DVocean* is equipped with state-of-the-art hydrographic measurement systems (MBES, sediment echo sounder, magnetometer, inertial navigation system, GNSS receivers). The assembly of these sensor systems is modular for flexible use. The hydrographic systems can be mounted on the bow, on the sides as well as on the stern and thus record data simultaneously. The roof can accommodate a laser scanner in addition to GNSS sensors, enabling additional recording of terrain above the waterline.

4 Concept and data acquisition

To reach the goals mentioned in section 1, a concept was developed including six key elements that should be worked on for the first version of the application (Fig. 1). These elements are summarised as follows:

- modelling a detailed 3D version of the exterior of the *DVocean* to be used as the standard avatar vessel for the simulation,
- simulate basic ship behaviour (floating) and movement (steering, acceleration) to navigate around the 3D environment,
- design a virtual environment with underwater elements (dynamic seafloor features, shipwrecks, cables) to provide diverse simula-

<i>DVocean</i>	
Propulsion	two outboards and bow thruster
Number of persons	maximal ten
Shipyard	Lübeck Yacht Trave Schiff GmbH
Completion of the ship	2019
Christening of the ship	28 May 2019
Hull length	8.0 m
Hull width	2.6 m
Maximum draught	0.9 m
Height above waterline	2.8 m

Table 1: Technical specification of the *DVocean*

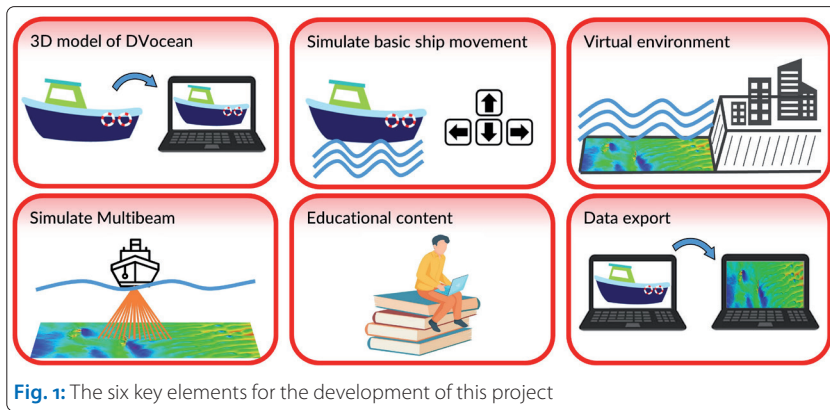


Fig. 1: The six key elements for the development of this project

tion scenarios as well as features above water (shoreline elements or harbour/city model) for better orientation,

- simulate the functionality of an MBES as well as the possibility to switch several parameters in real-time,
- provide additional educational content suited both for understanding the programme and gaining general knowledge about hydrographic surveying and
- develop an interface for data export to allow post-processing of simulated measurements as real data in external programmes.

After initial testing, it has been decided to additionally provide the option to digitally steer the research vessel *Atair* (operated by Bundesamt für Seeschifffahrt und Hydrographie), settle on the harbour of Hamburg as virtual environment due to availability of city model data as well as to choose simple XYZ format as data export format and focus on pro-

viding a data visualisation workflow in the open-source software QGIS for this first iteration of the programme. Additionally, the sensors GNSS and INS should be simulated. This concept furthermore emphasizes the development of a well-balanced prototype. Next to basic simulation functionality, this also includes comfort functions and ease-of-use systems such as a tutorial and a consistent user interface design while also paying special attention to maintaining low target system requirements to ensure improved usability for a wide audience.

The *DVocean* was scanned on 2 June 2021 using the terrestrial laser scanner IMAGER 5010 from Zoller & Fröhlich with a resolution of 6 mm at 10 m in the harbour of Wedel. 25 scans were registered to an entire point cloud, which served as a basis for the construction of a 3D model of the ship (Fig. 2).

Additional data sources for the education of the theoretical background include encyclopaedia content by the HCU Hydrography research group (Adhikari 2022; 2023), the »International Hydrographic Organization« (IHO 2005), »Federal Maritime and Hydrographic Agency of Germany« (BSH 2023), »HafenCity University Hamburg« (HCU 2023) as well as pictures and a technical drawing for modelling the *Atair* (BSH 2023) and sections of the LoD2 city model of Hamburg by »Agency for Geoinformation and Surveying Hamburg« (Landesbetrieb Geoinformation und Vermessung 2021).

5 Modelling and programming workflow

An early test programme was developed to determine the appropriate workflow and evaluate the programming environment's suitability for this



Fig. 2: Terrestrial laser scanning of the surveying vessel *DVocean* (top left and middle), the point cloud (top right) and the modelling process of the *DVocean*: from raw mesh (bottom left) to final model (bottom right)

project. The Unreal Engine 5 (UE5) was selected as the Integrated Development Environment (IDE) for this project due to its advanced capabilities in 3D rendering, physics simulation and providing extensive toolboxes for programming interactive elements. The workflow consisted of 14 steps:

- design basic block versions of all 3D elements,
- design basic environment features (simple seabed and water) in UE5 and implement physics simulation (object buoyancy, waves),
- implement basic ship movement,
- programme the MBES simulation,
- programme the GNSS and IMU simulation,
- programme the export functionality and
- programme the menus and basic User Interface (UI) components.

After the development of these seven steps, the core of the programme was set up. This was followed by going into further detail and implementing additional features:

- model a high-detail version of the *DVocean* and *Afair*,
- implement parameter switches to (de)activate instruments or adjust several resolution settings,
- design additional seabed features and implement the LoD2 model of the virtual environment of Hamburg and
- design and programme the encyclopaedia and the tutorials.

The finishing touches include:

- refining UI and add additional menus,
- optimise the performance by revising the code for MBES simulation, data storage and export and
- test and package the project for deployment.

Some of these steps shall be explained in more detail in the following.

The modelling of the *DVocean* is shown in Fig. 2. The meshed file from the scanning point cloud was taken as a basis to create a performance-optimised model of the vessel. The polygons focus around the high detail areas. The final model consists of about 21,000 polygons.

The physics simulation – especially the buoyancy behaviour – has been implemented with a specialised plug-in of UE5. To reduce calculation time, the simulation treats the modelled geometry only as visual representation. The actual physics simulation only takes into account four pontoon points – two at the front and two at the back of the vessel. These pontoons have a size, a mass and damping coefficients that need to be tweaked according to the real vessels size, mass and its buoyancy behaviour.

The simulation of the MBES starts with simulating a »true« beam that returns the actual distance between the instrument and the reflection point in the simulation. Based on water properties, this

value is transferred into a travel time value. Now, a second beam is simulated. This time, however, all the applied inaccuracies, errors and uncertain parameter settings (e.g. wrong GNSS or IMU values, inaccurate sound velocity profile values, etc.) are applied. Combined with the travel time from the first beam, this results in a (more or less accurate) point coordinate for the simulated reflected signal. This simulation is repeated for each beam of the array, according to the specified parameters for swath width, number of beams per ping as well as ping frequency.

An internal database temporarily stores the coordinates and timestamps. When the data volume in the internal database reaches a certain threshold, the data gets automatically exported in an XYZ file format, using the timestamp of the first coordinate for identification. The export can also manually be triggered by the user. In addition, each programme run also exports the true bathymetric data in a coarse resolution for the whole survey area for later comparison with the simulated results.

To provide context for orientation, an LoD2 model of the buildings and the harbour surrounding the Elbe in Hamburg from »Elbpark Entenwerder« in the east up to the »Elbphilharmonie« in the west was implemented and edited for performance optimisation, based on the data provided by LGV (Landesbetrieb Geoinformation und Vermessung 2021). Fig. 3 shows the extent of the virtual environment of Hamburg harbour that can be surveyed in this simulation. However, the environment is solely intended for orientation purposes. Several areas needed to be altered, particu-

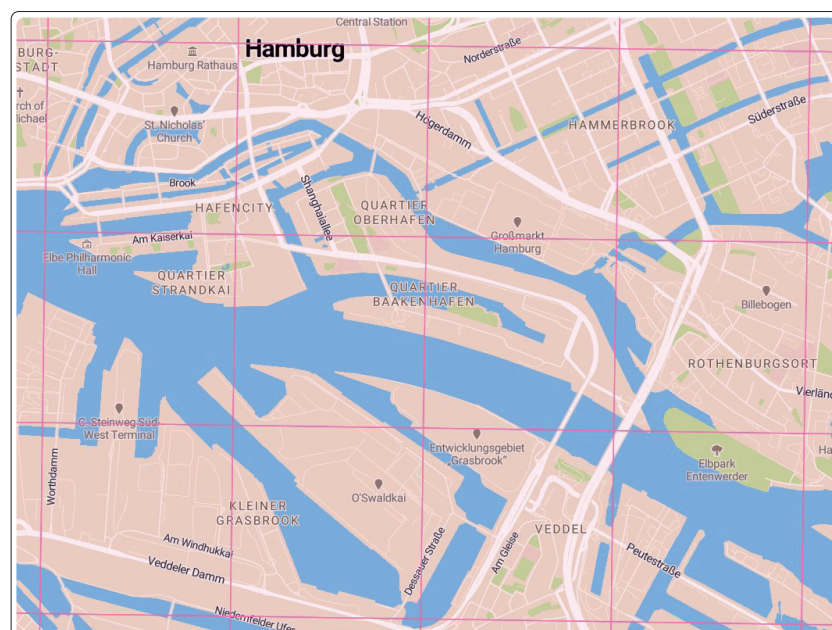


Fig. 3: The simulated area covers about 4 km from east to west and about 2.5 km from north to south (HCU Geodatenportal, map background: OpenStreetMap). Twelve 1 km x 1 km city model files in DWG format (shown here as pink grid) were used for the harbour environment

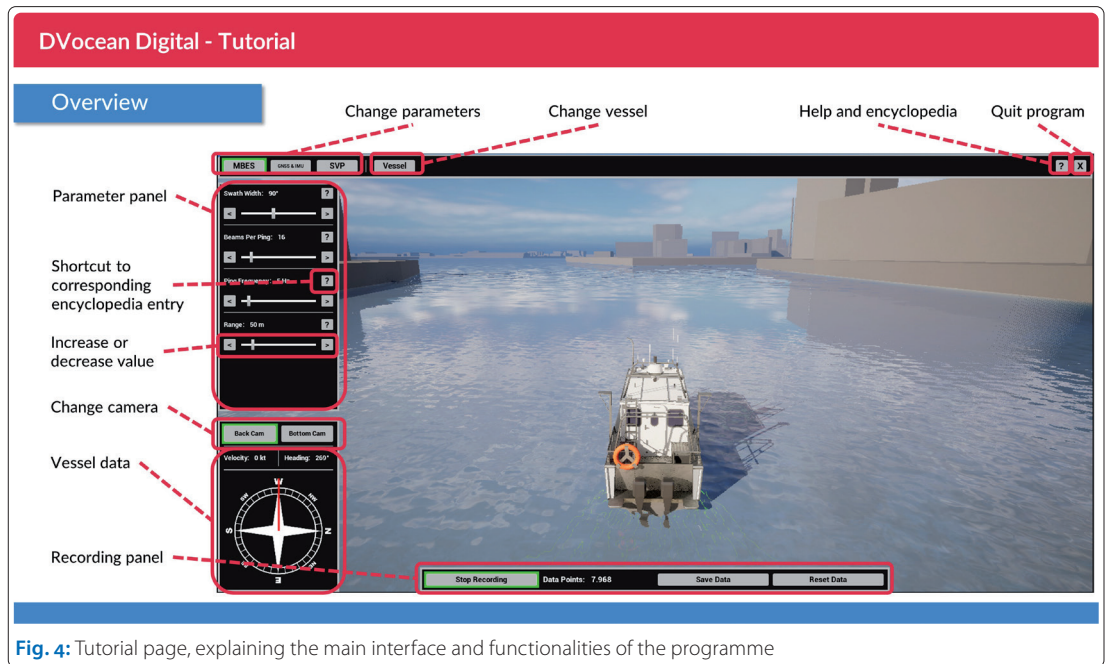


Fig. 4: Tutorial page, explaining the main interface and functionalities of the programme

larly the bathymetry in this area, which intentionally does not reflect reality. Instead, it has a high depth variation and a dense population of seafloor features such as cables and shipwrecks. This highlights this programme’s focus on learning, offering users a wide array of interesting features to investigate in a reasonable amount of time.

6 Results and example analysis

The prototype »DVocean Digital v1« is a stand-alone programme for Windows PC platform with a size of about 800 MB. It does not require any additional software to run. All required components are included within the programme folder. The users can choose between two vessels (*DVocean* and

Atair) which are integrated in the virtual environment of the Hamburg harbour. In addition to the simulation of the water and the ship itself, three sensors are simulated: GNSS, IMU and primarily an MBES. The simulating and learning features allow users to adjust eight different sensor parameters in real-time, a built-in encyclopaedia for hydrographic topics that is accessible from the corresponding instrument or parameter panels as well as a data storage and export system that allows the user to export the collected data in XYZ files for further analysis in external programmes.

Fig. 4 displays the main interface along with an explanatory overlay from the tutorial. The ship can be steered with the arrow keys of the keyboard. A panel in the lower left corner provides the user with basic information about heading and speed. Above that, the camera view can be switched between »Back Cam« (steering mode) and »Bottom Cam« (instrument mode), with the latter making the water surface transparent and visualising every beam of the MBES. A panel at the top lists the menus for the different instruments, for switching the vessel, the encyclopaedia and ending the simulation. The instrument menus consist of sub-panels that offer parameter switching functionality. The lower menu bar at the bottom of the screen shows information about the data recording status, buttons for starting and stopping data recording as well as for resetting and exporting data.

As mentioned in chapter 4, QGIS has been chosen as the programme for further simple data analysis for providing an easy workflow for data exchange with other programmes. Fig. 5 shows a small example project being visualised within QGIS. The application includes a tutorial on how

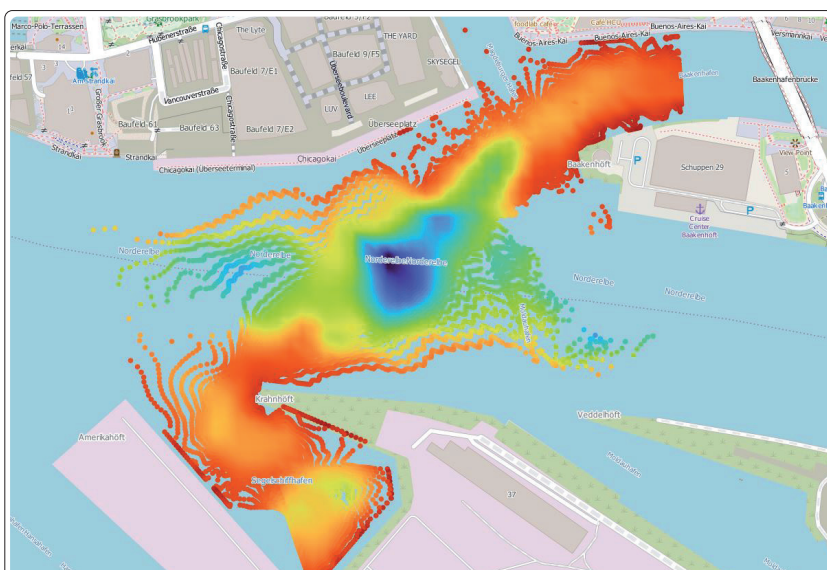


Fig. 5: Example data set in QGIS. Individual simulated coordinates can be seen as well as the effect of the wave simulation on the MBES data. (Note that the bathymetric data is not realistic. Map background: OpenStreetMap)

to set up QGIS for data import, visualisation and analysis.

Because parameters can be changed in real-time during the simulation, users can rapidly experiment with various settings to survey a feature of interest. Fig. 6 provides an example, where a shipwreck is surveyed with different MBES and sound velocity probe (SVP) parameters.

7 Conclusions and outlook

In the project »DVocean Digital« (in German: »Virtuelles Vermessungsschiff«) the prototype »DVocean Digital v1« has been developed as a stand-alone programme. The prototype is intended to be tested thoroughly by HCU hydrography students and staff in the winter term of 2023/24. Their feedback will provide a roadmap for both potential quality and quantity updates in future versions.

In addition to the built-in encyclopaedia, a key feature for learning is the possibility to change various parameters and observe the consequences in real-time as shown in chapter 6. The students thus gain a deeper understanding about how changes in the swath width, the number of beams or the frequency change the resolution of their simulated data set. What happens when GNSS or IMU are not properly calibrated? How would this data set look like with a different SVP? Visual insights that are usually impossible such as looking underneath the vessel in clear water and observing beam paths while altering their parameters offer additional opportunities to enhance the students' understanding about hydrographic topics.

As it stands, some limitations have to be kept in mind when using this prototype. Some key aspects from the hydrographic education at the HCU are not yet represented in the simulation. This includes, for example, simulating the water column as a single layer instead of a multi-layer system with a diverse SVP. In addition, the simulated ship's floating and steering behaviour needs further improvement to more accurately resemble their real-world counterparts. For future versions, several work packages should be developed with high priorities as follows:

Qualitatively, the simulation depth can be improved. Next to addressing the above-mentioned limitations, additional parameters for more instrument control as well as for the environment (other survey areas, adjustable depth, different seafloor sediment types and thus reflection characteristics, salinity and temperature) and further visual real-time feedback options (expanded camera options, additional visualisations of beams and depth-coded reflection points, data graphs in the UI) can be added.

Quantitatively, the key features can be expanded with a wider range of options: a greater variety of vessels, more simulated instruments (e.g.

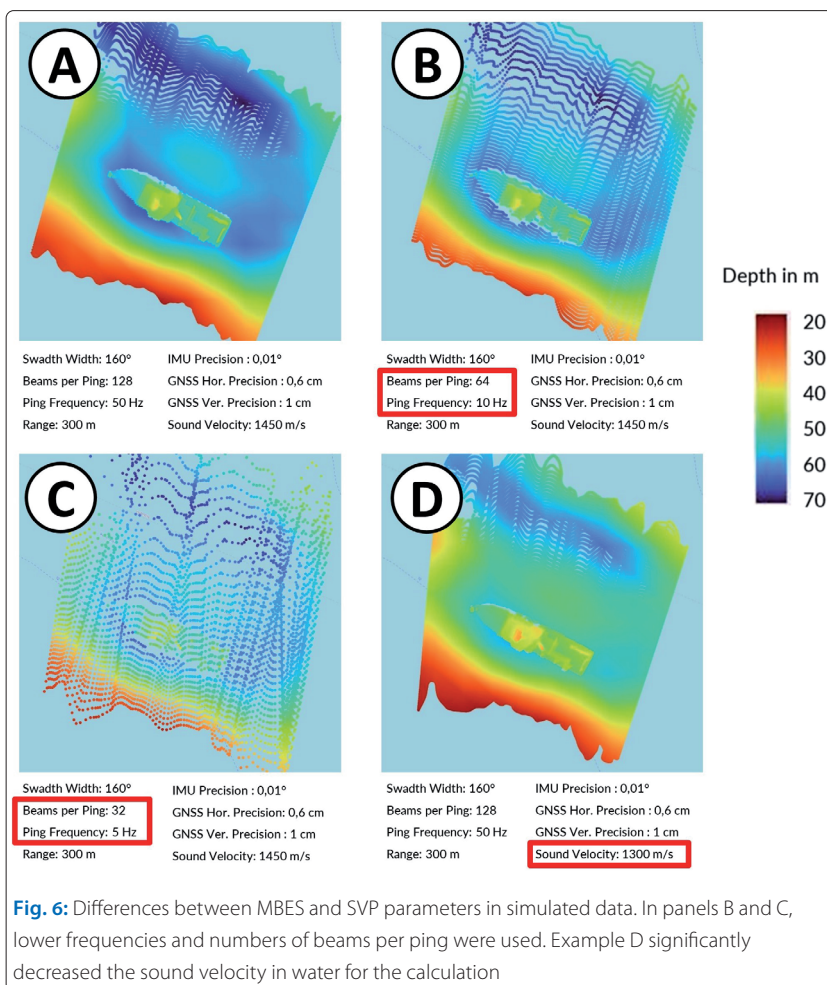


Fig. 6: Differences between MBES and SVP parameters in simulated data. In panels B and C, lower frequencies and numbers of beams per ping were used. Example D significantly decreased the sound velocity in water for the calculation

side-scan sonar, sediment echo sounder and laser scanner), more media types for knowledge transfer (e.g. enhancing the encyclopaedia with more audiovisual content and further background reading material). Potential additional features might include a survey planning mode, import functionality for waymarkers set in an external programme, an autopilot option and more export file types for compatibility with other post-processing software.

We see a high potential in this simulation software and its concept to be a valuable addition to both education and research in hydrography. Thanks to its emphasis on visual feedback, explaining and simplifying complex concepts, it also provides opportunities for use in outreach and scientific communication with the interested public. //

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