MINISTRY OF EDUCATION AND TRAINING
**HANOI UNIVERSITY OF MINING AND GEOLOGY**

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# RESEARCH THE SCIENTIFIC BASIS FOR BUILDING 3D MODELS OF SEABED TERRAIN TO SERVE SUBMARINE OPERATIONS IN VIETNAMESE WATERS

**Major: Surveying and Mapping Engineering**
**Code: 9520503**

**SUMMARY OF THESIS FOR DOCTOR OF GEOGRAPHIC AND MAPPING ENGINEERING**

**HA NOI, 2024**

The project was completed at the **Department of Advanced Geodesy, Faculty of Geodesy - Mapping and Land Management, HaNoi University of Mining and Geology**

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The thesis is defended before the school-level Thesis Evaluation Council, meeting at the HaNoi University of Mining and Geology, Duc Thang Ward, Bac Tu Liem District, Hanoi City at … .. … ..2024

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# INTRODUCTION

## 1. Urgency of the subject

The East Sea plays an important role in the task of building and protecting the Fatherland, and is the gateway for Vietnam to trade with regional and international countries. The islands and archipelagos in the East Sea, especially the Hoang Sa and Truong Sa archipelagos, not only have significance in controlling passing sea routes, but also have important strategic defense significance from afar. with our country. The Navy, including the submarine force, plays a core role in carrying out the task of firmly protecting national sovereignty at sea. Therefore, the necessary requirement is to fully utilize the strength of this force both in combat and in combat readiness training. It is necessary to ensure battlefield data and separate 3D terrain model data to serve combat operations at sea with high accuracy and detail, corresponding to each type of mission.

Today, with the development of science and technology, 3D models have become more popular in the country and around the world. Many agencies and units inside and outside the military have conducted research and built 3D models for different tasks, bringing great efficiency in both economic and national security and defense. However, there are no solutions for specific submarine operations, especially with 3D models of the seabed terrain.

Therefore, the topic *"Research on the scientific basis for building 3D models of seabed terrain to serve submarine operations in Vietnamese waters"* is very urgent.

## 2. Research objectives

The goal of the thesis is to establish a scientific basis for building a 3D model of seabed terrain to serve the operations of submarines in

Vietnamese waters, and to build a 3D model of seabed terrain for the experimental area. on a scientific basis that has been built.

**3. Subject and scope of research**

Research subjects: multi-beam depth measurement data, side-scan hydroacoustic data, backscatter data, 3D models and methods for building 3D models of seabed terrain.

Scope of research: Research and build 3D models of seabed terrain to serve the operations of Vietnamese submarines, and build 3D models of seabed terrain for a few experimental areas in Vietnam's waters.

**4. Research Methods**

Research methods used include: methods of collecting documents and data; methods of analysis and synthesis; comparative method; information technology methods; modeling methods; experimental method.

**5. Defense arguments**

**Argument 1**: The 3D seabed terrain model is built according to the multi-resolution mesh model method and the spatial quadrilateral mesh model with edges being parametric curves, based on the use of data combination. Multi-beam echo sounder and Side Scan Sonar data most realistically depict the actual surface of the seabed.

**Argument 2**: The sediment classification method from hydrographic data sources achieves good accuracy, improving the visualization of 3D seabed terrain models to serve submarine operations in Vietnamese waters.

**6. New points of the thesis**

- Proposing methods and algorithms to build 3D models of seabed terrain for submarine operations: Method to optimize 3D models using multi-resolution mesh and method to build 3D models using mesh quadrilateral with edges that are parametric curves.

- Proposing a sediment classification method to build a 3D model of sediment cover, visually representing the surface of the seabed topography.
- Proposing a process diagram for building a 3D model of seabed terrain for submarine operations.

**7. Scientific and practical significance**

Contribute to supplementing the scientific basis for building 3D models of seabed terrain.

Build 3D models of seabed terrain with high accuracy, close to the real surface and presented in the most intuitive way, serving submarine combat tasks such as training, combat readiness exercises, …high efficiency.

**8. Document and data base**

The thesis uses relevant domestic and foreign research projects, field data collected by the Surveying, Charting and Marine Research Team in the Nha Trang-Khanh Hoa sea area, Ninh Thuan sea, and Song Tu-Truong Sa sea.

**9. Structure of the thesis**

The structure of the thesis includes 3 chapters and is illustrated by 18 tables, 108 drawings and graphs, 13 appendixes with calculated data, 8 published research works and a list of 87 references.

# CHAPTER 1. OVERVIEW OF RESEARCH SITUATION AND CONSTRUCTION OF 3D SEA-FLOOR TOPOGRAPHY MODELS

## 1.1 3D model of seabed terrain

3D terrain modeling is a modern computer graphics technique that provides the ability to represent the three-dimensional space of the land surface with high accuracy and detail, creating realistic models that accurately reflect the terrain. physical and topographical characteristics of a particular area. Through 3D terrain modeling, one can explore space from many different angles, helping to create a comprehensive view of the surrounding environment.

**1.2 Some details about submarines and submarine operations**

Submarines serve as an important force of the navy, contributing to strategic deterrence by suddenly and quickly appearing or being invisible below the ocean surface. Vietnam's Kilo 636 class submarine is an upgraded version of the original Kilo class submarines, combining improvements in acoustic stealth features, navigation capabilities and advanced fire weapons.

**1.3 Requirements for geodetic and oceanographic data to ensure submarine operations**

Measurement and survey work to create topographic maps of the seabed is carried out to ensure maritime safety as well as other activities of surface and underground vehicles. Depending on the survey and measurement tasks serving the Navy's vehicles, different standards apply. The classification of requirements and level of seabed topographic survey is based on the following factors: Level of requirement for specific tasks (such as training, waiting for engines, and cruise), Level of importance of construction, project or water area (including maritime density and intended use). At the same time, also consider the depth of the water area and the complexity of the bottom terrain, thereby determining requirements related to the accuracy of determining coordinates and depth, and requirements for maximum coverage. bottom surface, as well as requirements for measuring methods and equipment.

## 1.4 Status of research and construction of 3D models of seabed topography, classification of seabed surface sediments in the world and in Vietnam

In the world, there are many research projects that have applied different methods in building 3D models in general, as well as applying 3D in navigation for surface navigation. However, research works go deeper into mesh construction techniques, creating model surfaces, improving model visualization, as well as serving submarine navigation. Current research projects are only in small areas of research nature, while projects serving submarines are highly confidential documents so they are very difficult to access.

For seabed sediment classification, countries with advanced hydrography have effectively applied seabed sediment classification from multi-beam backscatter data and side scan images. However, very few works apply classification results to improve visualization for 3D seabed terrain models.

In Vietnam, research on building 3D terrain models takes place in a variety of directions such as using data obtained from different data acquisition technologies, researching to improve accuracy. of 3D models, researching technological solutions to build and display 3D models. However, the problem of building a 3D model of the seabed terrain, using hydroacoustic technology to scan the sides to identify objects for 3D model building, technology as well as techniques and solutions to build 3D models. Little or no mention of seabed topography.

The use of multi-beam backscatter data and flank scan images in seabed surface sediment analysis has not been widely researched and applied in both the military and civilian world.

### 1.5 Issues that need further research

From the results of synthesis and analysis, it can be seen that research around the world on building 3D models of seabed terrain has been deployed quite extensively, but combining with sediment data to improve Model visualization is not effective. In Vietnam, there are very few research projects on building 3D models of seabed topography and using hydrometric data to classify sediments. The thesis researches and solves some of the following issues:

- Research and propose methods to optimize 3D mesh on the basis of multi-beam depth measurement data to build a model close to the actual surface of the seabed.

- Research on methods to visually represent the seafloor surface from multi-beam backscatter data and side scan sonar, combined with representing geographical objects.

## CHAPTER 2. SCIENTIFIC BASIS OF METHOD OF BUILDING 3D SEA-FLOOR TOPOGRAPHY MODELS

### 2.1 Select mathematical basis in establishing 3D seabed terrain model

In building 3D models of seabed terrain, use a flat perpendicular coordinate system to represent elements. Due to the specific characteristics of technological equipment and maritime combat characteristics of the Navy, the coordinate system chosen for use at sea is the WGS-84 coordinate system. Choosing to use the Mercator projection in collecting seabed topographic data to ensure direction retention, the depth system is the lowest sea surface in the area to ensure the safety of maritime activities.

### 2.2 Methods of collecting seabed topographic data

Collecting seabed topographic data currently uses the following common methods: using available data sources; Direct depth measurement is used for pole and beam measurements; single beam depth measurement; multi-beam depth measurement; flank scanning; Lidar; satellite depth measurement technology; Gravity anomaly technology...In particular, multi-beam depth measurement and side scanning are two popular methods of collecting terrain data in our country.

**2.3 Requirements for data used to establish a 3D model of seabed terrain**

2.3.1 Some characteristics of collecting depth data of multi-beam echo sounders

Depth density directly affects the quality of the established digital seabed terrain model. Different topographic data acquisition methods yield different depth point densities. Among them, the multi-beam echo depth measurement method is currently one of the methods of acquiring data with the highest point density today.

2.3.2 Level of detail of depth measurement points in 3D model creation

Data collected from the multi-beam depth measurement system is dense, ensuring good conditions for establishing a digital model of the seabed topography. The collected depth point will be processed and discarded if it is wrong, so it will have a density lower than the ideal condition. In addition, in the case of seabed topography data collected by other methods such as single-beam measurements and low density, it is necessary to use the interpolation method to increase point density; or in cases where it is necessary to generalize the terrain, with too thick a density of point data, the calculation and construction of the model will be difficult, so it is necessary to thin the data. After evaluating the collection density of many depth measurement systems, the thesis proposes requirements for depth point density before establishing a 3D terrain model as shown in the table below:

*Table 2. 3 Table of requirements for detailed depth point density before establishing a 3D seabed terrain model*

| No. | Depth range (m) | Point density (m) |
|---|---|---|
| 1 | 0 ÷ -5 | 0,10 |
| 2 | -5 ÷ -10 | 0,20 |
| 3 | -10 ÷ -20 | 0,50 |
| 4 | -20 ÷ -50 | 1,00 |
| 5 | -50 ÷ -100 | 2,00 |
| 6 | -100 ÷ -200 | 3,00 |
| 7 | -200 ÷ -300 | 5,00 |
| 8 | -300 ÷ -500 | 10,00 |

2.3.3 Image characteristics of side-scan hydroacoustics

Collecting side scan Sonar images requires determining the two most important parameters: range and resolution. Resolution determines the level of detail in the scanned image. It is divided into two types: vertical resolution (along-track), horizontal resolution (across-track) and scattering resolution. reverse. The scanning range will determine the survey scope, it depends on the operating frequency of the device. The higher the frequency, the smaller the scanning range and vice versa.

2.3.4 Requirements for representing geographical objects on digital models

Just like fighting on land, submarines when deploying undersea operations need to firmly grasp information about geographical objects such as rocks, corals, flora and fauna, and underground structures. sea. All geographical objects need to show complete information about shape, properties, etc. on the digital model.

## 2.4 Method for building 3D models of seabed terrain

### 2.4.1 Some interpolation algorithms

Some popular interpolation algorithms such as weighted distance inversion, radial interpolation, global polynomial interpolation, local polynomial interpolation, Kriging, Cubic Spline... Through research, the thesis chooses 2 Interpolation algorithm: inverse distance weighted (IDW) and Cubic Spline to build a 3D model of seabed terrain. Weighted distance inverse interpolation is a discrete interpolation, often applied to data in large-scale, highly variable areas, such as seafloor topographic data. Cubic Spline is trend interpolation, used to build a smooth and continuous curve through a set of known data points, representing the most natural nature of the seabed topography.

### 2.4.2 Method for building 3D models using multi-resolution mesh

The multi-resolution mesh construction method aims to optimize input data, focusing on representing terrain details in shallow areas, steep terrain, and many dissections, and showing generalizations in other areas. deeper, the terrain is flatter, to achieve optimization while still ensuring accuracy in model building calculations. The 3D model optimization process in this case goes through the following steps:

1. Partition the input data according to terrain complexity, slope or depth.
2. Build a square grid in each area, the value of the grid size follows Table 2.3.

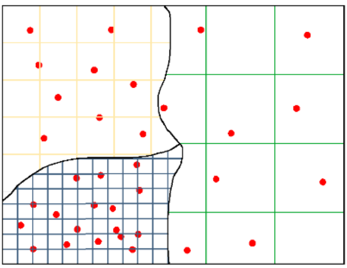


*Figure 2. 25 Building a grid in each area depending on the depth*

3. Depth interpolation for mesh points. Use the distance inverse interpolation algorithm to interpolate mesh points..

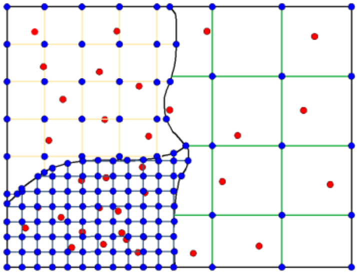


*Figure 2. 26 Distribution of bathymetry data and mesh interpolation using IDW*

4. Build multi-resolution mesh and surface structures of the model

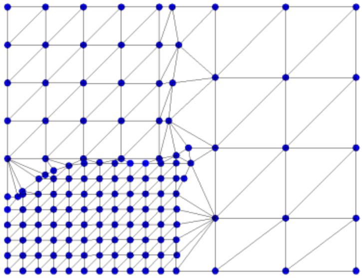


*Figure 2. 28 A multi-resolution mesh structure is constructed*

* Advantages of multi-resolution 3D mesh: Better and continuous model with different data densities, efficient construction process and easier data management, elevation values at nodes The mesh has higher precision than the grid mesh.

2.4.3 Method of building 3D models using a space quadrilateral mesh with edges as parametric curves

The space quadrilateral model is the model that represents the most realistic seabed terrain due to its continuously curved and smooth surface characteristics. To build a space quadrilateral model, you need to follow the following process:

1. Determine the ship's route based on the depth

2. Determine the routes adjacent to the ship route passing through the actual measured depth points.

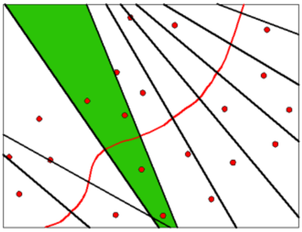


*Figure 2. 31 Identify areas to select points near the ship route*

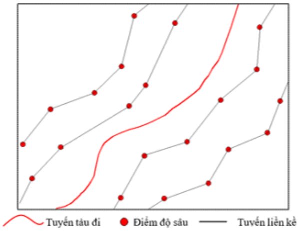



*Figure 2. 33 Identify routes adjacent to the ship route*

3. Construct a cubic-spline curve passing through a set of adjacent line points.

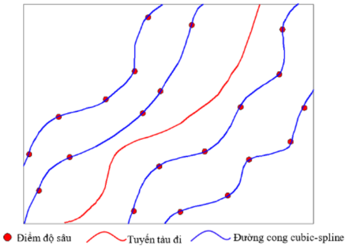



*Figure 2. 35 Cubic-spline curves pass through adjacent line points*

4. Determine the faces perpendicular to the travel route, cut the parametric curves at new locations

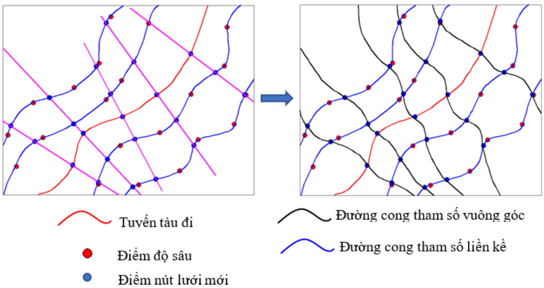



*Figure 2. 37 Nodes of a curved quadrilateral mesh*

5. Construction of curved quadrilateral mesh and parametric curved surface

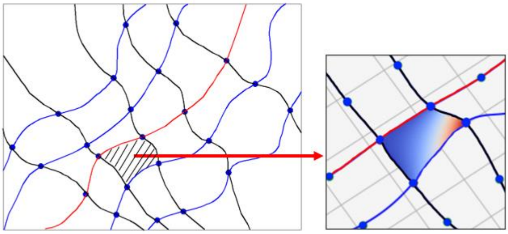


*Figure 2. 38 Space quadrilateral mesh and space quadrilateral curved surface*

** Comments, the space quadrilateral mesh has the following advantages::*

The model is continuous, showing the correct trend of the terrain. Compared to the TIN grid model, there will usually be errors in the shape of the terrain around the location of the triangle vertices. The model still ensures accuracy because the measured points are still retained on the parameter curves.

**2.5 Requirements for model accuracy after establishment**

To evaluate the accuracy of the established model, the graduate student uses the geodetic method to select depth measurement points that do not participate in building the model to check the established model and calculate the mean square error. . In addition, based on the construction results from commercial 3D modeling software such as Golden Software Surfer, Global Mapper, ArcGIS 3D Analyst... compare the mean square error results between commercial models. and the model according to the proposed research method.

**2.6 Method for visualizing 3D models of seabed terrain**

Information about terrain, geomorphology, and seabed sediment properties are extremely important in submarine combat operations. Therefore, research on visualizing seabed terrain in 3D modeling is a very necessary requirement, helping commanders get quick, accurate information and make decisions soon.

### 2.6.1 Sediments and sediment classification methods

Sediments are deposited particles, soil and rock materials produced by endogenous or exogenous geological processes or other natural phenomena. Sediment grain size is one of the basic characteristics of sediment. Clay is the type with the smallest particle size, followed by clay, silt, sand, gravel or pebbles. Based on the composition and size of sediment particles, people classify and determine the name of the sediment. There are many sediment classification scales, including the sediment classification scale of the International Hydrographic Organization with a total of 20 types.

### 2.6.2 Multi-beam backscatter data

Backscatter data is a type of data collected by multibeam depth sounding systems, used to determine seafloor surface sediments. In backscatter data there is information about the sound intensity level, which is the level of reflection of sound waves at the seabed surface. Each different layer of sediment will have a different level of reflection, which will depend on the level of reflection of sound waves to provide information about the type of sediment on the seabed surface.

### 2.6.3 Side scan sonar data

Side-scan sonars are used to map the seafloor for a variety of purposes, including creating maps and detecting and identifying underwater objects. They are often used to conduct surveys and archeology of the seabed. Combined with substrate samples, flank sonar can be used to classify seafloor sediments.

### 2.6.4 Sediment classification method

***a) Method for processing sediment data from backscatter data***

Before backscatter data from raw data can be used, further processing needs to be performed, including processing of depth data. Perform some basic steps such as: importing terrain data, checking histograms, creating initial mosaic images, extracting samples, analyzing incident angle response (ARA), creating final mosaic images and classifying . The principle is as follows: Assuming that the seabed surface is completely flat and uniform, when the multi-beam system emits sound pulses, the signal intensity received in the reflected sound pulse is in a position perpendicular to the bottom. The sea will be stronger with sound pulses emitted on both sides. Each type of sediment will have different backscatter intensity response characteristics at different incidence angles and sound frequencies, called the sediment interpreter. After processing, multi-beam field survey data will be compared with interpreted sample sets to determine the type of sediment to be searched for.

***b) Method for processing sediment data from side scan sonar data***

To be able to classify sediments from side scan hydroacoustic data, it is necessary to go through the following steps: 1. Prepare images; 2. Extract features and build a sample set for sediment interpretation; 3. Model training: Use the Decision Tree algorithm, a machine learning algorithm, to build a prediction model and classify data; 4. Create a classification image: The received classification image is an image in which the grayscale values of the pixels are within the predetermined classification indexes; 5. Vectorization and editing.

### 2.6.5 Solution for representing sediments and geographical objects in 3D models

Current related research works often use simple methods such as simple lighting models (e.g. shading), annotation methods and feature textures methods. Although these methods effectively distinguish different sedimentary regions, they have many limitations. Based on published research works, the thesis uses the advanced characteristic structure method to represent sediments in a 3D model of seabed terrain, proceeding as follows: 1. Construction of particle structures sediment: using photogrammetric measurements, creating white-balanced images, reconstructed into point clouds; 2. Enhance visual effects with 3-dimensional space mapping techniques and eliminate texture repetition effects; 3. Create and mix aquatic plants: Each sediment area has an ID as the base, corresponding to surface properties determined from analytical data, then overlaid accordingly; 4. Simulate the underwater environment by adjusting color temperature and white balance.

## 2.7 Propose a process diagram for building a 3D seabed terrain model for submarine operations

With the research results achieved, the graduate student constructed a process diagram to establish a 3D seabed terrain model as follows:

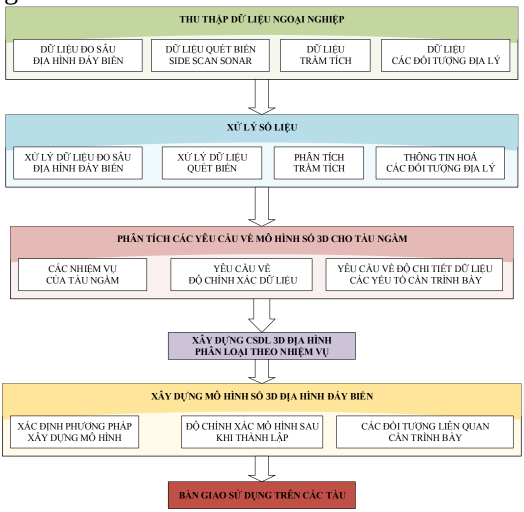



*Figure 2. 69 Process of building a 3D model of seabed terrain*

1. Collect field data: collect highly accurate data sources such as seabed topographic data, side scan data, hydrometeorology, etc.

2. Processing input data: Processing of data sources needs to be carried out according to the correct process, ensuring allowable errors for each type of data.

3. Analyze requirements for 3D models for submarines: To ensure effective submarine operations, it is necessary to specifically evaluate the submarine's tasks, and at the same time indicate requirements for 3D models when performing Performs tasks in waiting areas, lying on the bottom, traveling under the sea or any combat training and SSC missions of submarines.

4. Building a 3D seabed terrain database: The database system must ensure a Client - Server mechanism with a decentralized system, information security and classification of seabed terrain data according to tasks corresponding to the tasks. submarine warfare.

5. Build a 3D model of the seabed terrain: After having a standardized database for each task, select a method to build a digital model.

# CHAPTER 3. CONSTRUCTION OF A 3D MODEL OF THE SEA FLOOR TOP FOR SUBMISSION OPERATIONS

## 3.1 Area and experimental data

### 3.1.1 Introduction to the experimental area

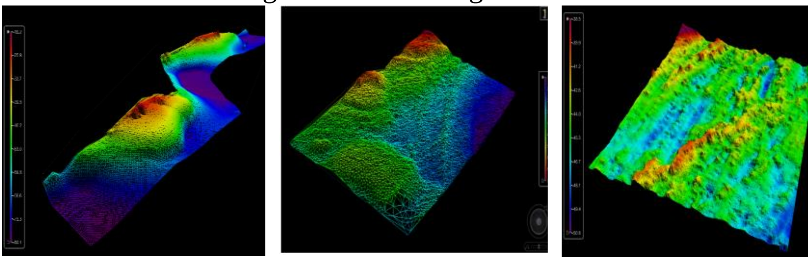
In this content, 3 areas have been selected with different geographical locations, typical for the nearshore area, the mid-shore area and the offshore area: The area of Nha Trang - Khanh Hoa sea (range of 5km x 10km, depth from 18-70 m), area of Ninh Thuan sea (range 3.5km x 3.8km, depth from 17-73m), coastal area of Song Tu island cluster in Truong Sa archipelago (range 1km x 4km, depth from 19m-80m). The areas selected for the experiment all have a high frequency of submarine operations, representing tasks such as waiting for engines, lying at the bottom, combat cruises…

3.1.2 Introduction to acquisition methods

The experimental data in the thesis was collected in 2014, 2019 and 2021, performed by the SeaBeam 1180 shallow water multi-jet measuring system, the Atlas Hydrosweep MD30 deep water multi-jet system, and the Side scanning device. Scan Sonar Klein 3000, CM2 is equipped on survey ships 888, 884 of the Marine Surveying and Charting and Marine Research Group/Navy General Staff. In addition, use Van Veen sampling bucket to directly collect sediment samples in the field.

## 3.2 Experiment in building 3D models of seabed terrain

3.2.1 Results of building 3D models using multi-resolution mesh

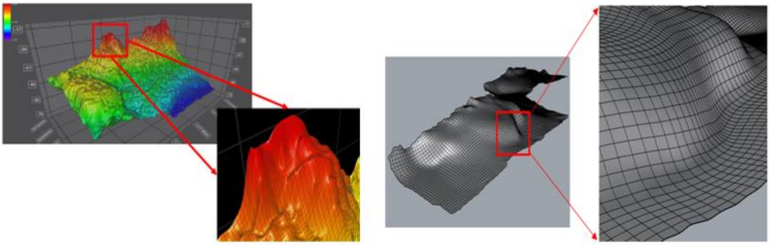


a) Song Tu b) Nha Trang c) Ninh Thuan

*Figure 3. 16, 19, 21 Multi-resolution 3D mesh model of 3 experimental areas*

3.2.2 Build a spatial quadrilateral mesh model with edges as parametric curves

Results of building a 3D surface model with space quadrilaterals:

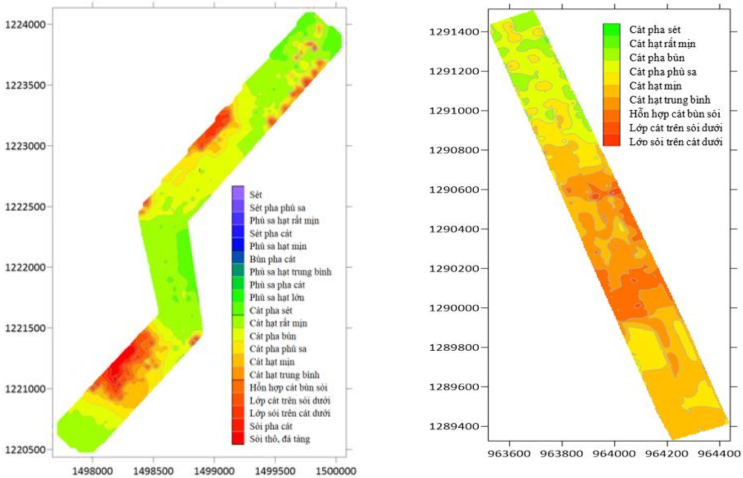


*Nha Trang - Khánh Hòa* *Song Tử*

*Figure 3. 22, 23 3D surface model with spatial quadrilaterals of 2 experimental areas Nha Trang and Song Tu*

3.2.3 Process and display sediment classification results from side-scan hydroacoustic data and multi-beam backscatter data

esults of sediment classification in the coastal area of Song Tu island cluster:




*a) Song Tu* *b) Ninh Thuan*

*Figure 3. 26, 27 Sediment classification results from hydrometric data*

### 3.2.5 Visual display of 3D seabed terrain model

After analyzing side scan images, classifying sediments, combining objects, building a 3D overlay model. 3D modeling results of the Gemini Sea sediment cover:

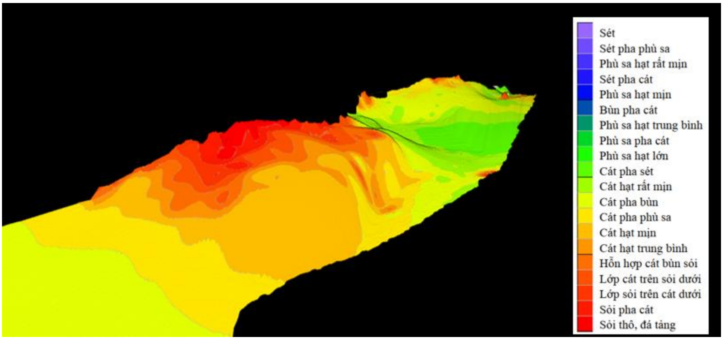



*Figure 3. 28 3D image of sediment cover in Gemini Island area*

### 3.2.6 Accuracy assessment

***a) Results of evaluating 3D model accuracy***

Based on the methods of evaluating model accuracy, the researcher calculated the mean square errors for the established models and had a comparison table as follows:

*Table 3. 1 Results of calculating the mean square error of the established models (unit: m)*

| Area / Method | Nha Trang | Ninh Thuan | Song Tu |
|---|---|---|---|
| Build with ArcGis 3D Analyst (TIN) | 0.26 | 0.34 | 0.54 |
| Multi-resolution mesh model | 0.13 | 0.27 | 0.41 |
| Space quadrilateral mesh model | 0.20 | 0.31 | 0.33 |

Through the table above, it can be seen that the two proposed methods of model building both have higher accuracy than the common TIN grid model. For areas with steep slopes and highly variable terrain, the spatial quadrilateral grid method is more reliable (such as the Gemini sea area). But with large areas and low density of detailed points, the multi-resolution grid construction method is more effective and more reliable (like the Nha Trang sea area).

***b) Results of assessing the reliability of sediment classification***

- **For the experimental area in the Song Tu Sea:**

Collected a total of: 31 bottom samples. Each substrate sample is collected in a separate container, labeled with information including: substrate type, coordinates, depth, particle size. The bottom material collected is mainly: fine sand, medium-grained sand, and small crushed coral.

*a) Cát hạt trung bình* *b) San hô*

*Figure 3. 30 Some sediment samples collected in the Song Tu Sea area*

From the results of processing multi-beam backscatter data and side scan images, compare them with actual collected samples to evaluate the reliability of the method, shown in Figure 3.31.

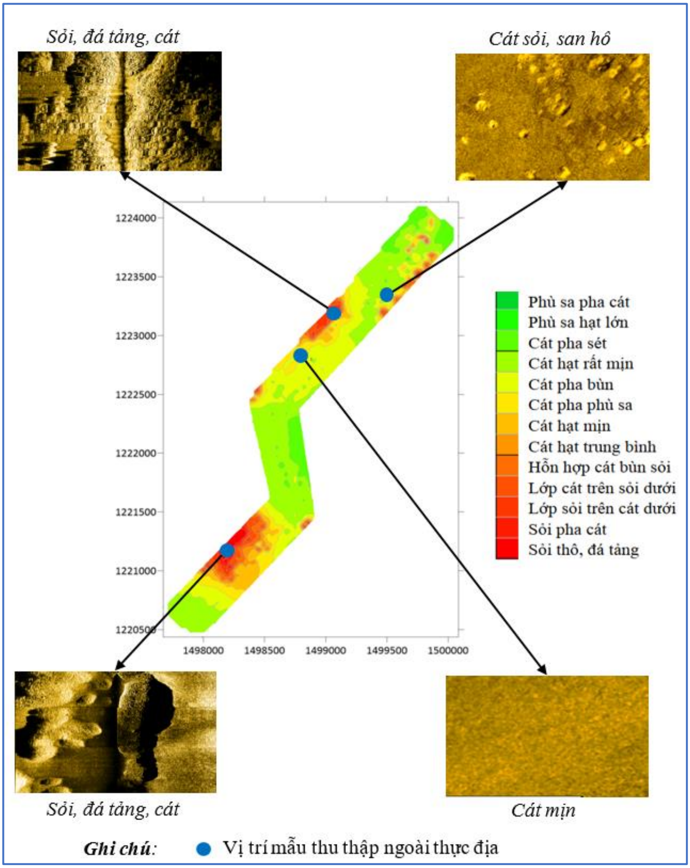



*Figure 3. 31 Compare sediment samples collected in the field with sediment classification results from backscatter data and side scan images*

In addition, high-resolution images taken by satellites in areas with many large rocks were used to compare with images obtained from side-scan hydroacoustics, and the results were highly similar. The results of calculating the confusion matrix are according to the table below:

*Table 3. 2 Confusion matrix for sediment classification results from backscatter data, side scan data with field samples in the Song Tu area*

| **Type of sediment collected in the field** | **Total number of samples in the field** | **Classification results from backscatter data and side scan sonar data** | | | | |
|---|---|---|---|---|---|---|
| | | The sand is very fine | Medium grain sand | Sand, mud and gravel | Sand mixed gravel | Coarse gravel, boulders |
| The sand is very fine | *6* | 6 | 0 | 0 | 0 | 0 |
| Medium grain sand | *8* | 0 | 7 | 1 | 0 | 0 |
| Sand, mud and gravel | *8* | 0 | 1 | 6 | 1 | 0 |
| Sand mixed gravel | *5* | 0 | 0 | 0 | 5 | 0 |
| Coarse gravel, boulders | *4* | 0 | 0 | 0 | 1 | 3 |
| **Total** | ***31*** | ***6*** | ***8*** | ***7*** | ***7*** | ***3*** |

From the above tables, the Kappa value is calculated to be 0.84, the average accuracy is 87.10%.

- **For the experimental area at Ninh Thuan beach:**

The figure below depicts the correlation of sample collection and sediment classification results from multi-beam backscatter data.

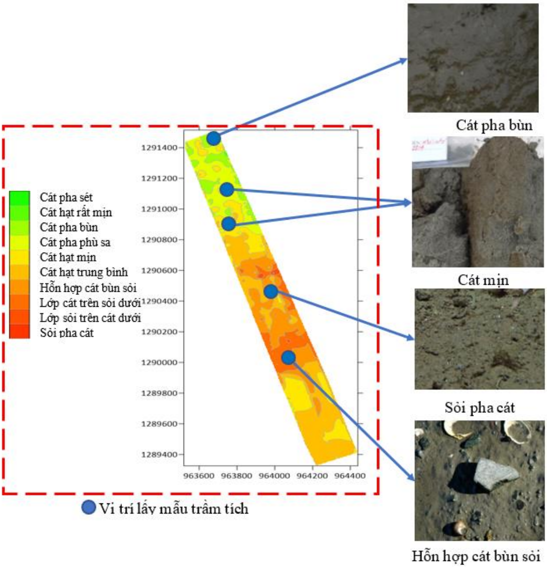



*Figure 3. 34 Comparison of field samples with classification results from backscatter data and side scan data at Ninh Thuan sea*

In the Ninh Thuan sea area, 25 field sediment samples were collected. The result of calculating the Kappa value is 0.78, the average accuracy is 84%.

### 3.3 Develop software to create 3D models of seabed terrain

From the theoretical basis of chapter 2 and experimental data, graduate students proceed to build an independent program, with the following functions: 1) Read original multi-beam data; 2) Build multi-resolution depth mesh, 3) Build spatial quadrilateral mesh; 4) Display 3D model of seabed terrain; 5) Accuracy assessment; 6) Simulate the seabed surface.

## CONCLUSION

The thesis draws some of the following conclusions:

1. Today, with the development of science and technology, 3D modeling is now very popular both domestically and around the world.

Many agencies and units inside and outside the military have conducted research and built 3D models for different tasks and brought great efficiency both in terms of economics and national security and defense. However, the above 3D solutions are not suitable for the specific operations of submarines. Measurement and survey work to create topographic maps of the seabed is carried out to ensure maritime safety as well as other activities of surface and underground vehicles. For some areas requiring high accuracy, in addition to multi-beam depth measurement that scans the entire seabed terrain, it also requires the use of Side scan sonar data to detect maritime obstacles. The PhD student proposed two methods to build 3D models of seabed terrain: the method of optimizing the 3D model using a multi-resolution mesh and the method of building a quadrilateral mesh model with edges as reference curves. Numbers help create 3D models to ensure optimal time, performance, scope, accuracy and increase the level of detail of the model.

2. When visualizing seabed terrain, there will be many difficulties compared to models on land because of different environmental properties. The study proposes procedures for classifying sediments from hydrographic data sources, creating sediment cover surfaces and side scan images on the seabed topographic surface to improve the visualization and vividness of the model. established, this is a very important scientific contribution of the thesis.

3. The proposed process diagram for building a 3D model of seabed topography from multi-beam echo sounder data and side-scan hydroacoustic data satisfies the requirements for establishing a digital model. Experimental results show that the built models fully meet the accuracy requirements. With the built 3D model, it can be used in many different fields, especially in navigating vehicles in the navy, typically guiding submarines.

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