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Optimizing Sea-Spike Detection and Removal in Bathymetric Data: A Case Study of Bintulu, Sarawak

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1.0 Introduction

Single-beam echo sounders remain popular for seabed mapping because they possess affordable cost and user-friendly design and deliver essential services for marine navigation and coastal management and resource conservation. **High-amplitude echoes known as sea-spikes** can severely harm depth measurement precision by disrupting readings thus lowering the overall data accuracy.

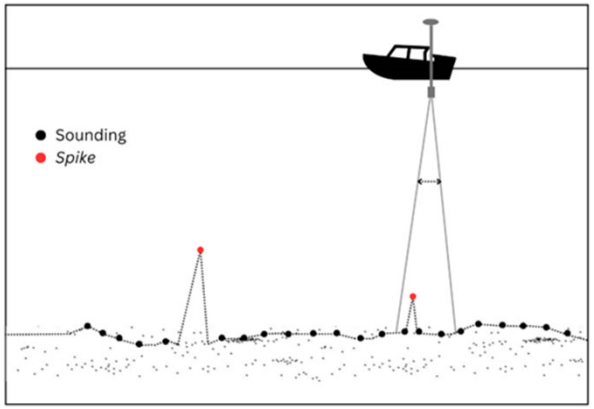


Figure 1: The sea-spikes contained in the bathymetry data collection

The manual processing method for outliers produces subjective results and demands excessive labor which makes it difficult to accomplish trustworthy data processing.

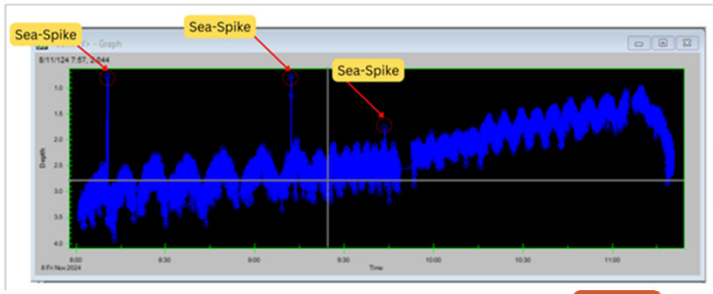
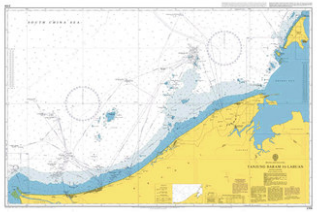


Figure 2: The bathymetry data that contained spikes shown in Hydropro Nav Edit

1.2 Why This Matter?

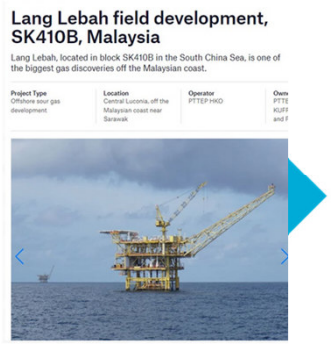


- **Safe Marine Navigation**

Sea-spike errors in bathymetric maps can misrepresent actual seabed depth, leading to grounding hazards for ships.

- **Disaster Risk Reduction**

Accurate bathymetry supports modeling of tsunami impact, storm surge, and flood pathways.

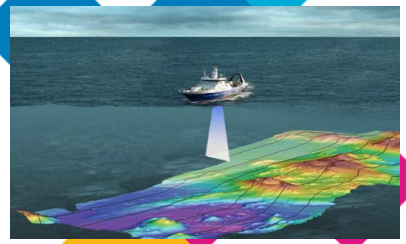


- **Coastal Engineering & Infrastructure**

Projects like dredging, pier construction, and coastal protection require precise seabed profiles.

- **Marine Environmental Monitoring**

Habitat mapping for coral reefs, seagrass beds, or fisheries depends on fine-resolution seabed data.



- **Resource-Limited Survey Operations**

Many small-scale hydrographic operations (e.g., in developing regions) use SBES due to its affordability.

- **Compliance with Hydrographic Standards**

SFS helps bathymetric data meet IHO S-44 standards, which is required for:
Nautical chart production
Survey certifications
Government-regulated marine infrastructure projects

1.3 Aim & Objective

To develop and validate a semi-automated filtering system (SSFS) that effectively detects and removes sea-spike outliers from bathymetric data collected using Single Beam Echo Sounders (SBES), in order to improve data quality and support compliance with International Hydrographic Organization (IHO) standards.

To analyze the limitations of manual sea-spike removal in SBES bathymetric datasets, particularly under challenging marine conditions.

To design and implement a semi-automatic filtering framework (SSFS) using:

- Mean Absolute Deviation (MAD) for statistical outlier detection
- Median Filtering for data smoothing
- Mixed Filtering to combine both for optimized performance
- To apply the SSFS system to real-world bathymetric data collected from Pantai Tanjung Batu, Bintulu, Sarawak, and process it for cleaning and correction (including tidal adjustments).

2.0 Study Area & Dataset

Study Area:

- Tanjung Batu Beach, Bintulu, Sarawak, Malaysia
- Size: 500m x 1000m
- Depth range: 1.5m to 3.8m (above MSL)

Survey Tools:

- SBES with Teledyne Odom Hydrotrac Echo Sounder
- Trimble DGPS System
- High-density point collection at 2-second intervals (5m apart)

Figure 3: shows the study located in the Pantai Tanjung Batu, Bintulu, Sarawak, Malaysia

3.1 SSFS Framework

System developed in 4 phases:

1. Data Collection & Mapping
2. MAD, Median & Mixed Filter Design
3. Filtering + Tidal Correction
4. Validation using RMSE, MAE & TVU

Filtering parameters:

- MAD factor thresholds
- Radius/window size selection

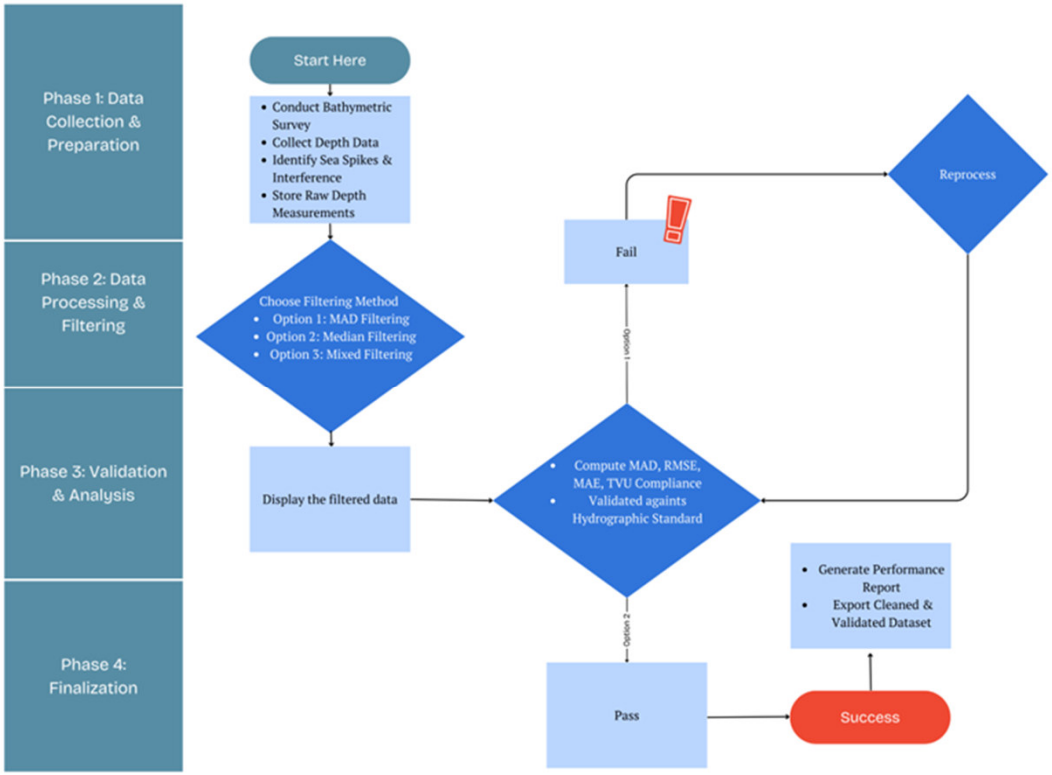


Figure 4: The flowchart of the system development SSFS

3.2 Filtering Algorithms

Mean Absolute Deviation (MAD): Detects outliers using deviation from local mean

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(x_i - \mu)^2}$$

Where N is the total number of data points,

Xi represents the depth value at the i-th point

μ is the mean depth within a defined radius (e.g 10 meters)

Source: (Devore, J. L., 2020)

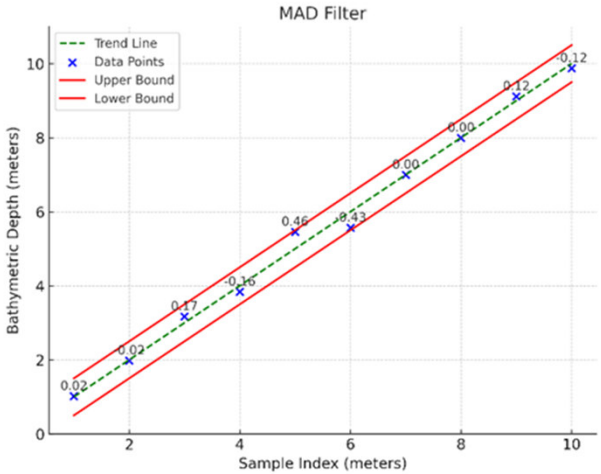


Figure 5: The illustration of MAD filter in outliers' detection

Median Filter: Smooths data with center value in sliding window

$$y_i = \text{Med } x_i \triangleq \text{Med}\,(x_{i-v}, \ldots, x_i, \ldots, x_{i+v}),\quad i \in Z$$

Where $v = \frac{n-1}{2}$ *and* Z denotes the set of all natural numbers.

Meanwhile, the 2-D filtering that applied to a surface (seabed), the median filter response is:

$$y_i = \text{Med } x_{ij} \triangleq \text{Med}\,[xi + rj + si(r,s) \in A], (i,j) \in Z^2$$

Where A is the support window of size L×L.

Source: (Zhang et al., 2023)

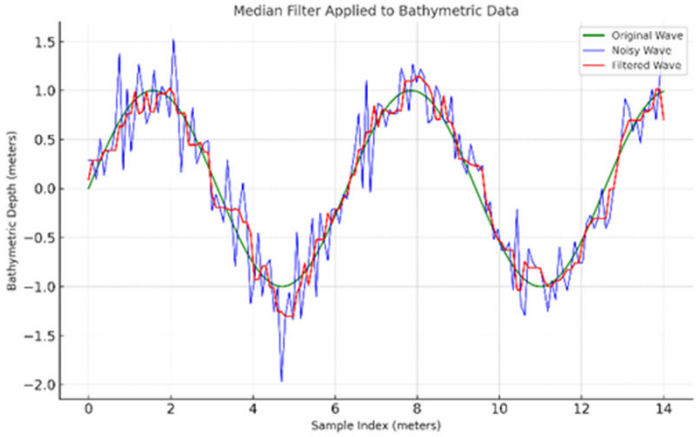


Figure 6: The illustration of median filter application in bathymetric data

Mixed Filter: Applies MAD, then smooths with Median

Tuning via MAD factor:

- Low (0.2), Medium (0.5), High (0.7)

3.3 Validation Approach

Validation Metrics:

- **RMSE: 1.4188m (sensitive to large deviations)**
- **MAE: 0.9663m (uniform error metric)**
- **TVU compliance: 59.39% (Order 2)**

Compared against IHO S-44 Edition 6.1.0 standards.

$$TVU_{max}(d) = \sqrt{a^2 + (b \times d)^2}$$

Where a represents the depth-independent uncertainty
b is the depth-dependent coefficient
d is the measured depth

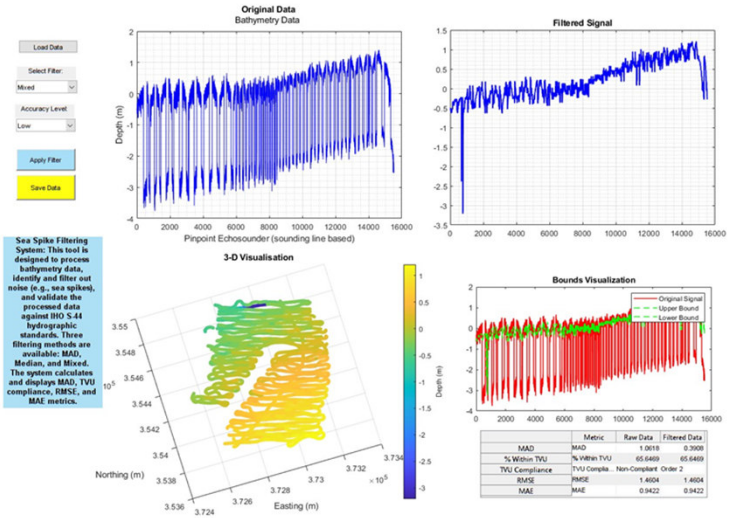
Minimum Bathymetry Standards for Safety of Navigation Hydrographic Surveys

Criteria	Order 2	Order 1b	Order 1a	Special Order	Exclusive Order
Area Description (Generally)	Sea floor is considered adequate	Not critical for the expected surface shipping in the area.	Not critical, but concerns for surface shipping may exist.	Underkeel clearance is critical.	Strict minimum underkeel clearance and manoeuvrability criteria
Depth THU [m] + [% of depth water]	20 m + 10% of depth	5 m +5% of depth	5 m + 5% of depth	2m	1m
Depth TVU (a) [m] and (b)	a = 1.0 m b = 0.023	a = 0.5 m b = 0.013	a = 0.5m b = 0.013	a = 0.25m b = 0.0075	a = 0.15m b = 0.0075
Feature Detection [m] or [% of Depth]	Not Specified	Not Specified	Cubic features > 2m, in depths down to 40m; 10% of depth beyond 40m	Cubic features > 1m	Cubic features > 5m
Feature Search [%]	Recommended but Not Required	Recommended but Not Required	100%	100%	200%
Bathymetric Coverage [%]	5%	5%	≤ 100%	100%	200%

Source: IHO Standards for Hydrographic Surveys, S-44, Edition 6.1.0, October 2022

4.0 Results

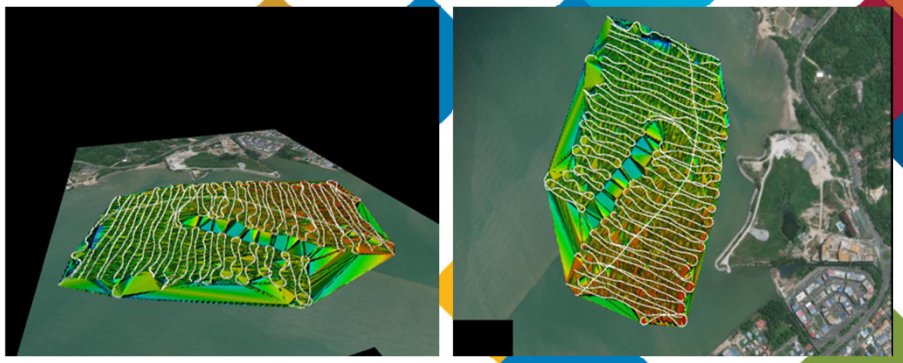
Depth Range Improved:
- **Raw: 3.8m to 1.5m**
- **Filtered: 3.2m to 1.0m**



Method	Mixed & MAD		Median	
Metric	Raw Data	Filtered Data	Raw Data	Filtered Data
MAD	1.0618	0.4314	1.0618	1.0478
Percentage within TVU (%)	59.39	59.39	99.67	99.67
TVU Compliance	Non-compliant	Order 2	Non-compliant	Non-compliant
RMSE (meter)	1.4188	1.4188	0.1213	0.1213
MAE (mater)	0.9663	0.9663	0.0567	0.0567

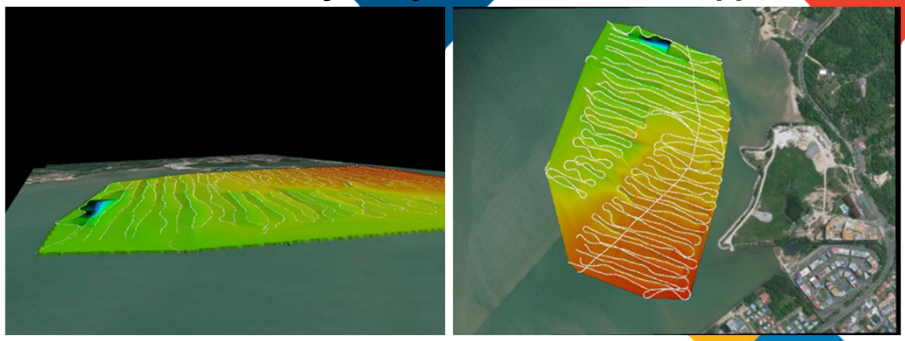
BEFORE

Unfiltered Bathymetry Data in Global Mapper



AFTER

Filtered Bathymetry Data in Global Mapper



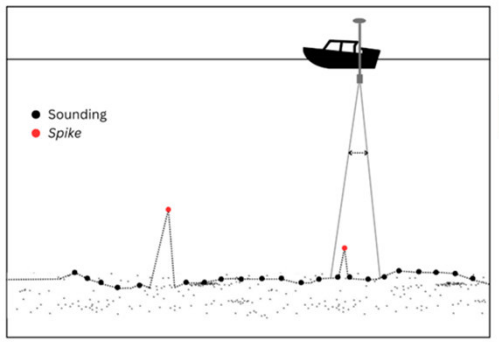
5.0 Conclusion

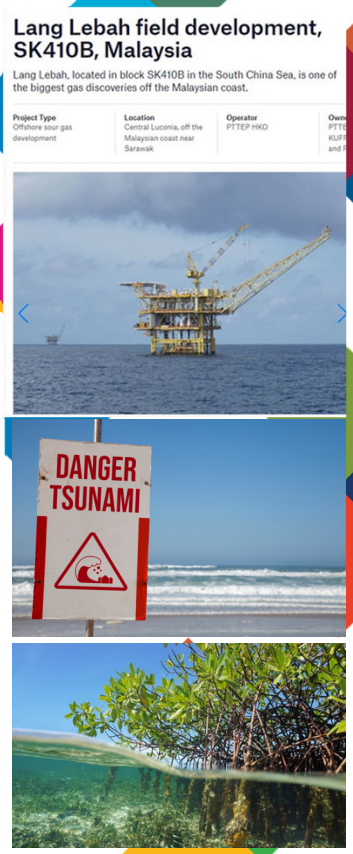
The Sea-Spike Filtering System (SSFS) is a semi-automated tool for removing outliers in SBES bathymetric data.

It combines MAD, Median, and Mixed Filtering to reduce sea-spike noise while preserving true seabed features.

Tested in Bintulu, Sarawak, the system reduced MAD from 1.0618 to 0.4314 and achieved 59.39% IHO Order 2 compliance, with RMSE and MAE sustained at acceptable levels.

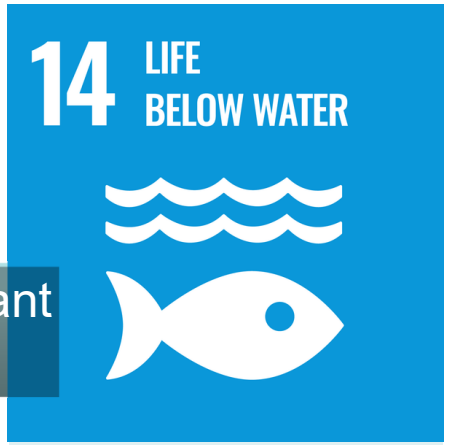
Though it falls short of Order 1a/Special Order standards, SSFS is reliable for general surveys—especially in resource-limited environments—and can be improved with ML, adaptive filters, and multi-frequency sonar.





The most relevant SDGs related to the presentation and theme of this session

1st relevant SDG



2nd relevant SDG

3rd relevant SDG

SUSTAINABLE DEVELOPMENT GOALS

International Federation of Surveyors supports the Sustainable Development Goals

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THANK YOU

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