Side-scan sonar image processing: Seabed classification based on acoustic backscattering

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Abstract. The smoothness of vessel traffic flow is the most important thing in the shipping industry of port. Traffic problems are commonly solved by development and maintenance programs. Seabed conditions in the port-channel should be known to be considered in port development and maintenance programs related to port efficiency, safety navigation, and berthing. The objective of this paper is to characterize seabed into several classes of geological features. The Seabed condition and characteristics are classified based on image processing of side scan sonar data. The image processing will extract pixel value parameters; intensity, entropy, and standard deviation. Classification use combination of these pixel view parameter to define each class. Seabed classification has been successfully carried out in Teluk Bayur Port and classified into five classes, sandy silt, silty sand, fine sand, coarse sand, and rocks or reefs. Indication of crack or shallow structure was also identified. These results of classification are necessary to verify by sediment sampling and visual inspection, and then it should be reclassified to become a valid classification.

Keywords: Acoustic, Characterization and Classification, Seabed

1. Introduction
Seabed characteristics are important to know for port development or maintenance activities. The development of ports sometimes involves dredging a deep channel through reef or rock areas for safe navigation and berthing, while maintenance activities must be done periodically at the port with rapid sedimentation rates. Sedimentary deposits, reefs, rocks, and sediment structures are some seabed characteristics related to dredging activities [1]. In the port areas, these seabed characteristics are able to define by drop core and shallow drill or estimated from contrast intensity of acoustic backscatter; Multibeam data, and side-scan sonar imagery.

Seabed characterization at the large port area is effectively done by acoustic survey before dropping core or shallow drill; moreover, the drop core is possible only implemented at some location to verify the result of seabed characterization estimated from side-scan sonar imagery. In order to increase the level of confidence of estimation, the acoustic survey is better to include several acoustic methods; sub-bottom profiling, multibeam echosounder, and side-scan sonar. Each method can be utilized for mutual verification.

Geological features related to grain size, sediment structure, or rocks will provide different acoustic responses. Each response is implicitly described in its acoustic backscattering [2-7]. The Spatial
distribution of acoustic backscattering of side scan sonar data is shown in the form of imagery. If this spatial distribution is processed, it should reveal geological features information.

In this publication, authors try to characterize seabed at port-channel and classify it into several classes of geological features. Characterization applied to side-scan sonar imagery by using grayscale of image processing. Some geological features are verified by other acoustic methods such as multibeam and sub-bottom profiling. Secondary data obtained from previous publications, drop core data, also used instead of ground truth checking. This paper aims to characterize seabed into several classes of geological features and propose several drop core locations or shallow drill locations to validate the result of classification. The validated classification of the seabed could be used as a consideration for development and maintenance activities.

2. Methodology

2.1. Materials and study area
Primary data uses are from side-scan sonar, multibeam and sub-bottom profiling data, while secondary data use a sparse distribution of drop core around the port area [8]. Data distribution is shown in Figure. 1. Primary data were acquired related to maintenance and development of Teluk Bayur Port, Padang, West Sumatera Province, in 2020. Acoustic instruments used included the Starfish side scan sonar system, the Odom Echotrack MB2 multibeam echosounder, and Stratabox chirp system, total line survey is about 21 km. Side-scan data has been processed for geometric and radiometric correction, and the output data is an imagery dataset in grayscale format. Multibeam echosounder and sub-bottom profiling data were also processed to verify the features identified on the side scan imagery dataset. A secondary dataset will be used to classify results from the side-scan imagery dataset as a ground truth check.

Drop core used secondary data that had been taken in 2008, and only one drop core data was available in the line survey. Seabed characterization will be conducted with data limitation then the result will be used to propose new drop core data.

Figure 1. The study area showed the distribution of the side-scan sonar line and drop core.
2.2. Methods

Seabed classification was processed with image processing that applied to side-scan sonar imagery as an output of data processing. Side-scan sonar imagery was computed from acoustic backscatter intensity that converted into pixel value of a grayscale image. It means that the backscatter intensity value is represented by a bright or dark pattern on the image. The pixel value of the grayscale image has a value ranging from 0 – 255. Image processing uses three extracted values from the imagery dataset; intensity, entropy, and standard deviation. These three extracted values will be used as the basis for classification. Grayscale image of side-scan sonar divided into small window size, at the beginning it should determine the windows size and windows step for the initial stage of image processing, then calculated the intensity, entropy and standard deviation for the size of every window. After the intensity, entropy, and standard deviation values were obtained, they were classified using the classification learner module in Matlab. Create a distribution map of each value and overlaid all these distribution maps and create a classification polygon based on the result of classification. The drop core data has been obtained in the form of substrate classification results.

2.2.1. Intensity. Average intensity represented by average brightness simply to calculate for defined windows size, the average defined as follows:

\[
B(j) = \frac{\sum_{i=1}^{N} I(j)}{N}
\]  

(1)

Where \( B(j) \) is the intensity of the image, \( I(j) \) is the value in the \( j^{th} \) pixel of the size of the windows of image, windows size and windows step must be defined before calculating the entropy, smaller windows size gives more detailed classification.

2.2.2. Entropy. Entropy is a statistical measure of randomness. Its value is maximum when most pixel value image in the middle of range value and minimum when pixel value very dark or very bright. Entropy calculated on image processing [9] is defined as follows:

\[
\epsilon(j) = \sum_{i=1}^{N} I(j) \cdot \ln(I(j))
\]  

(2)

Where \( \epsilon(j) \) is the entropy of image, \( I(j) \) is the value in the \( j^{th} \) pixel of the size of the windows of image, windows size and windows step must be defined before calculating the entropy, smaller windows size gives more detailed classification.

2.2.3. Standard Deviation. A standard deviation computes the variation of grayscale values in the texture analyzing- window [10]. Standard deviation is defined as:

\[
\sigma_i = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} X_i - \bar{X}}
\]  

(3)

Where \( X_i \) is the value in the \( i^{th} \) pixel of the sub-image, and \( \bar{X} \) is the average of all the pixel values.

After each parameter was obtained by image processing, the classification was applied using classification learner that available in Matlab, Figure 2. Classification produced based on these three parameters with control point is sediment type from secondary data, flowchart classification by using image processing shown in Figure 2. The stage begins with the processing of SSS data, mosaicking, and creating a greyscale image. The qualitative interpretation was carried out against the SSS image to determine the number of classes. Subsequently, initial image processing was implemented with certain parameters, windows size, windows step, and a number of classes. Image processing provides values of intensity, entropy, and standard deviation. Each value is transformed into maps that give an overview of intensity and entropy distribution. Image processing results were supervised with qualitative
interpretation and sediment types derived from grain size analysis of drop core. In case it does not match, we repeat image processing with some adjustment parameters (Figure 3).

![Graph](https://via.placeholder.com/150)

**Figure 2.** Classification applied using classification learner in the Matlab.

![Flowchart](https://via.placeholder.com/150)

**Figure 3.** Flowchart of seabed classification through image processing.

3. Results and Discussion

Side-scan sonar imagery is shown in a grayscale image (Figure 4). High intensity of backscatter acoustic shown as dark pattern related to the higher the intensity, while low intensity shown as a bright pattern.
It is known that the backscattering phenomena are related to seabed roughness or hardness that may be directly related to grain size, sedimentary structure, rock, and other hard features such as wreck or anchor. [2-3, 5-7, 11]. The rough or hard bottom will provide high backscatter intensity of acoustic return, while the soft bottom will provide low backscatter intensity [12]. On image processing, backscatter intensity represents by its pixel value. The pixel value ranges between 0 to 255. The lowest pixel value has the brightest image, while the highest pixel value becomes close to black.

In this study area, seabed based on acoustic backscattering that has been verified with one drop core sample has been classified into five classes; sandy silt, silty sand, fine sand, coarse sand, and rocks, Figure 5. Classification has been done based on a combination of three-parameter image processing; intensity, entropy, and standard deviation. Sandy silt has the lowest intensity ranges between 2 to 118, and the highest entropy ranges between 167 to 255. On the contrary, rock has the highest intensity ranges between 193 to 254, and the lowest entropy ranges between 1 to 105. The standard deviation for each class almost has the same value except sandy silt class that has a higher standard deviation value. The five classes are defined as shown in Table 1.

There are overlapping values for intensity, entropy, and standard deviation because the threshold values for the classification are actually not the vertical line (Y-Axis). Detailed classification can be seen in Figure 2. The orange color is associated with sandy silt. The light brown color is associated with silty sand. Purple is associated with fine sand. The light green color is associated with coarse sand, and light blue is associated with rocks or reefs.

### Table 1. Five groups of seabed classification through image processing.

| No | Class        | Intensity | Entropy   | Standard Deviation |
|----|--------------|-----------|-----------|--------------------|
| 1. | Sandy Silt   | 2-118     | 167-255   | 1-209              |
| 2. | Silty Sand   | 87-143    | 183-234   | 1-115              |
| 3. | Fine Sand    | 114-181   | 137-207   | 1-131              |
| 4. | Coarse Sand  | 161-206   | 96-152    | 2-153              |
| 5. | Rocks        | 193-254   | 1-105     | 5-134              |

Drop core sediment of "Sed_13" was the only ground truth that was available to verify and define classification through image processing in the study area. “Sed_13” sediment core based on grain size analysis classified into sandy silt, texture sediment distribution in the port area classified into three types sediments; sandy silt, silty sand, and gravel [8], shown in Table 2.

Water depth at the study area varied between 6 to 14 meters, the shallow area located in the northern part and the deep area located in the southern part. Seabed morphology is relatively flat except for some areas in the southern part where there is a high that is associated with rocks or reefs. In the study area, morphological changes were also identified lengthwise along the study area due to previous dredging activities.

### Table 2. Sediments sample and types in the study area.

| No | Drop Core Sample Name | Sediment Type |
|----|-----------------------|---------------|
| 1. | Sed_1                 | Silty Sand    |
| 2. | Sed_2                 | Sandy Silt    |
| 3. | Sed_3                 | Gravel        |
| 4. | Sed_4                 | Silty Sand    |
| 5. | Sed_5                 | Sandy Silt    |
| 6. | Sed_6                 | Silty Sand    |
| 7. | Sed_7                 | Silty Sand    |
| 8. | Sed_8                 | Silty Sand    |
Optimum classification has been obtained by these five classes. The classes have defined four types of sediment and one type interpreted as a rock. The result of classification has shown that sediments distribution covered seabed predominantly sandy silt to fine sand, it corresponds to sediment types derived from grain size analysis of drop core sediments. The final selection of image processing parameters was appropriate to the qualitative interpretation that has been done (Table 1). Each class parameter has an overlap value to make the boundary between the two classes relatively smooth.

The image processing also depends on the selection of windows size and step, and detail classification requires smaller windows size and steps. In this case, the size of the windows is ten, and the windows step is 8. The intensity parameter determines the class properly on dominant dark or bright windows, but it would not properly work on windows with that high randomness of the pixel value. The windows with high randomness would better determine the class assisted by entropy and standard deviation parameter. High randomness windows also include the boundary area at every feature. [13-14].

Seabed classification has been verified with drop core sediment “Sed_13” and qualitative interpretation that has a high level of confidence, particularly the darkest image in the southern part that is interpreted as rocks or reefs. The interpretation results are confirmed by multibeam data in Figure 7a and Figure 7b and sub-bottom profiling in Figure 9. Multibeam has shown around the body of the outcrop as high as 5 meters and elongated body as high as 4 meters from normal seabed. Sub-bottom profile has shown that the outcrop is an acoustic basement – bedrock appears on the seafloor, Figure 9a, while at elongated body identified a crack or shallow geological structure, Figure 9b.

The rock and coarse sand class is also distributed in the area which has undergone morphological changes due to previous dredging, Figure 8a. Sidescan sonar image has shown dark image, high intensity, elongated from north to south, Figure 8b. This area is doubtful to be classified as a rock because there is no evidence from the sub-bottom profile but still possible as coarse sand. High intensity may occur in this area due to artificial slopes formed by dredging activities. This area will be proposed to become a candidate for drop core locations.

The character of the seabed around the port is necessary related to development and maintenance activities, safety navigation, and berthing. Seabed classification can be used as initial information to characterize the seabed. Furthermore, it can be made into valid information by carrying out verification activities, such as seabed sediment sampling and visual inspection at an outcrop area, especially in the area that has indications of the crack or shallow structures, either divers or remotely operated vehicle (ROV). Sediment sampling is supposed to be carried out at several locations, at least in every class and in the areas that have been dredged before. The result of verification will be used to make valid classification by reclassification process.

Mechanism of sediment accumulation will depend on the amount of material coming from the source, the distance from the source, the amount of time that sediment has had to accumulate, how well the sediments are preserved, and the amounts of other types of sediments that are also being added to the system. Sediment textures of fine and coarse sand are rarely found around the rocks-reefs class. If this phenomenon is related to the mechanism of the sedimentation process, it can be assumed that the rocks which have been identified are not associated with sandstones or reefs. Another possibility that causes these occurrences is that the dominant source rocks originated from the mainland of Sumatera [15].

| No | Drop Core Sample Name | Sediment Type   |
|----|----------------------|-----------------|
| 9. | Sed_9                | Silty Sand      |
| 10.| Sed_10               | Sandy Silt      |
| 11.| Sed_11               | Silty Sand      |
| 12.| Sed_12               | Sandy Silt      |
| 13.| Sed_13               | Sandy Silt      |
| 14.| Sed_14               | Gravel          |
Figure 4. Sonar imagery, the dark color represents high intensity; the bright area represents low intensity.

Figure 5. Seabed classification, based on image processing, use three parameters, intensity, entropy, and standard deviation.

Figure 6. Water depth – MBES, the water depth range between 6 - 14 meters. The red color is shallow water depth, and blue is deeper water depth.
Figure 7. (a) Morphological feature interpreted as outcrop from multibeam data; (b) The same feature was recorded on side-scan sonar data.

Figure 8. (b) Morphological changes due to previous dredging activities; (b) The same feature was recorded on SSS, some areas recorded as high intensity.
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Figure 9. (a) An outcrop identified appear on the seabed; (b) A crack or shallow geological structure is identified below an outcrop.

4. Conclusion
Seabed classification has been successfully carried out and conforms to qualitative interpretation, and proper parameters selection is the most important thing when doing image processing. The seabed is classified into five classes; sandy silt, silty sand, fine sand, coarse sand, and rocks or reefs.

Result classification can be used as initial information for the development and maintenance of the port, but it would be better to verify by seabed sediment coring at every class of classification and visual inspection at an outcrop, particularly in the areas that have an indication of crack or shallow structure. Verification can change the initial classification to become a valid classification.

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