Hydro-acoustic Survey and Edge-detection method in Investigation of a Passenger Vessel Accident in East Java, Indonesia

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Abstract

As an archipelagic country, the shipping sector in Indonesia becomes crucial in delivering goods inter-island, and due to increasing transportation demands. However, that industry encounters some challenges of the ocean environment that could lead to vessel accidents. An investigation into the accident is crucial since this is related to the properties, environment, and life disadvantages. The wrecks of sinking vessels also could harm the environment, providing an obstacle to the sea passage hence increasing the risk of a shipping operation. A proper and comprehensive investigation needs to be carried out to identify the factors that contribute to the accident, so then risk mitigation can be taken to prevent re-occurrence. In the case of missing foundered or sunken vessels, an underwater examination is a must, so the investigator understands the real condition of the vessel. Although diver and underwater robotic surveys are still prevalent in the investigation, these techniques have limitations due to visibility and location. By contrast, those limitations can be addressed using hydro-acoustic technologies, which are capable of providing high-resolution underwater images and digital elevation model (DEM) bathymetry. Thus, the use of these technologies is promising in-vessel accident investigation, both in-situ investigation, and post-processing analysis. This paper describes an examination of the use of side-scan sonar and multibeam echosounder in-vessel accident investigation. The use of slope feature and edge-detection technique are also investigated concerning the investigation. Results indicate that those acoustic systems can contribute to the inquiry effectively by portraying some underwater objects as the accident suspects. Besides, slope and edge detection methods also produce expectant outcomes to support underwater object detection and investigation.

Keywords: Vessel accident, Hydroacoustic, Side-scan sonar, Multibeamechosounder, Edge Detection

INTRODUCTION

The shipping industry is one of the vital parts of the transportation sector in Indonesia. However, a high-risk ocean environment could be a severe challenge in that industry and could lead to a vessel accident. Of the factors influence that accidents are collision, grounding, and sinking (Weng & Yang, 2015). Therefore, vessel accidents become one of the prominent problems in the shipping industry and could affect to loss of properties, environment, and people's life (Akyuz & Celik, 2014).In addition, another threat comes from the sinking vessel that could lead to shipwreck. Those shipwreck sites are vulnerable by the threat of damage due to the human activities such as mobile fishing, trawling, and dredging and the quantifying of this damage has not been finished recently (Brennan *et al*., 2012). Moreover, Masetti & Calder (2012) also asserted that the shipwrecks could contribute to marine pollution by releasing hazardous and toxicant materials from its corrosive body and other ship's component that could harm the environment. Thus, investigation and identification of shipwreck sites become mandatory to obtain a comprehensive causal report and analysis.

Although survey methods (e.g., diver and remotely operated vehicle/ROV inspection) are still common in-vessel accident investigation, these methods have some limitations particularly related to water visibility and location accessibility. In contrast, acoustic remote sensing technologies (e.g., multibeam echosounder and side-scan sonar) have demonstrated to lead a promising outcome in that regard. Acoustic surveying and mapping of the wreck site are aiming to examine the texture and stratigraphy of the wreck location and the seafloor surroundings. The distinction between areas of wreck archaeological interest and its surroundings can be

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useful for determining archaeological prospection (Thabeng *et al*., 2019).

Digital Terrain Model (DTM), as the main product of the multibeam survey, has been demonstrated as an effective tool in vessel investigation. Slope, as one of the derivation layers of Bathymetric DEM, could reveal the wreck location and distinguish its location with the surroundings (Micle *et al*., 2010). While the DEM is adequate in the visual examination of the wreck location, Slope is better to be used to quantify the seabed. Besides, side-scan sonar has shown its capability to portray underwater objects with the resolution of the sub-centimeter scale (Blondel, 2009). Thus, it could lead to an expectant result for vessel investigation. However, in regards to object detection purposes in side-scan sonar imagery, image segmentation is common to be used. Edge detection is one of the techniques in image segmentation that has demonstrated as an effective method in side-scan sonar image segmentation. Such research can be found in (Leros & Andreatos, 2016; Sinai *et al*., 2016). Yet its use in a vessel accident investigation is still limited. This paper describes a survey operation involving two underwater acoustical technologies of multibeame chosounder and side-scan sonar in a vessel accident investigation. Slope as a bathymetric data derivation product and an edge-detection of image processing method are also discussed to support the analysis of the investigation. Depicting and analyzing the environmental condition of a wreck-site is an essential action in examining the quality of remaining wreck debris.

MATERIALS AND METHODS

The study area is located in the Teluk Lamong, Surabaya, Indonesia (Figure 1). This area located in the Western Surabaya Ship channel. The channel characterized by dense vessel traffic, channel depth limitation, and numerous underwater hazards. Thus, authorized pilot guidance is mandatory, especially for vessels with more than 500 GT.

The survey was carried out from 17 to 19 December 2015 and started from the capsize location of the MV Wihan Sejahtera to the site of the vessel’s wreck. This survey was a joined collaboration between the Indonesian National Transportation Safety Committee (KNKT) and Technology Center for Marine Survey, Agency for the Assessment and Application of Technology (BPPT). A Reson Hydrobat Composite multibeam system and An Edgetech 4200 FS side-scan sonar system were used during the survey. A Coda Octopus F180 GPS and Inertial Motion Unit (IMU) receiver were utilized to provide a highly accurate position and motion data (heave, pitch, and roll). Those systems were integrated into PDS2000 software to record the multibeam data. All of the survey equipment was installed onboard a wooden port transport boat with a 12.5 m of length, 3 m of wide, and 1 m of draft.

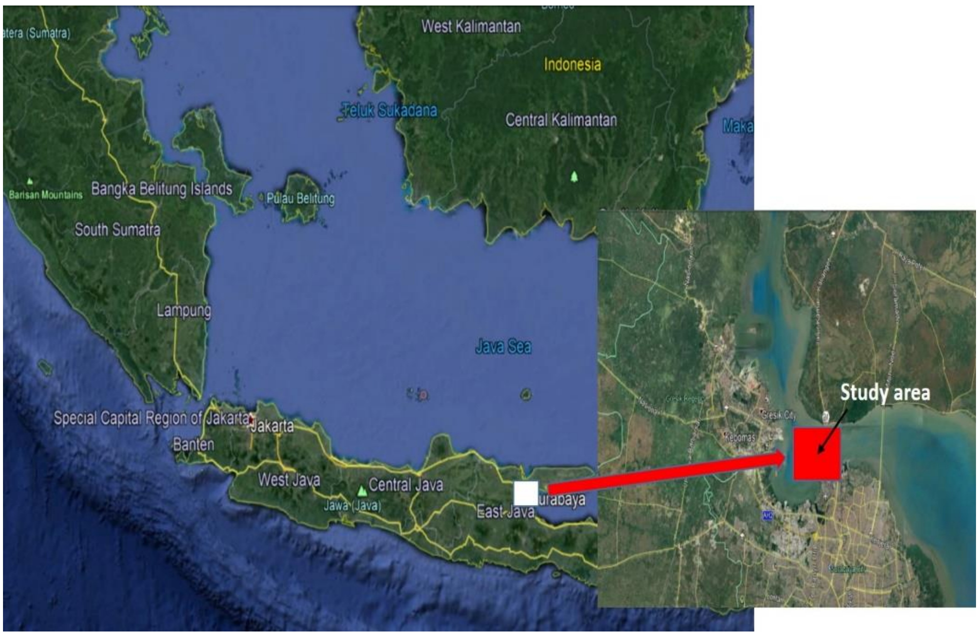


Figure 1. Study area

Chronological Occurrence

As summarized from the accident investigation report(KNKT, 2015), initially two days before the accident, a dredging vessel of MV DBD Cai Jun I shifted from Teluk Lamong jetty to the anchorage area. After reaching a position of 7°10'26.82"S / 112°41'19.98"E with the water depth of 20 m, this vessel then dropped a 40 m of spud pile on the left side of the vessel. After a couple of minutes, the vessel's crews assumed that the pile was already reaching the seabed. However, the pile was released uncontrolled into the water and detached from its holder on the vessel in which finally disappeared into the water. Unfortunately, this incident was not reported immediately to the port authorities, nor there was no hazardous sign to warn other vessels passing that location.

On 16 November 2015 at 08.55 am (local time), MV. Wihan Sejahtera departed from Jamrud jetty, Tanjung Perak port of Surabaya. Eighteen minutes after that, this vessel encountered a strong vibration, and immediately the vessel speed decreased from 9 to 7.7 knots. The vessel heeled 5˚ to the starboard side at five minutes after that and the heel worsen to 30˚ and increased gradually, yet the vessel kept moving slowly as the master attempted to maneuvered to a safer location. After the evacuation of all passengers, the vessel continued to capsize and totally sank at 10.07 am. One day after that accident, the KNKT conducted a depth survey at the wreck location and obtained that the depth was around 20 – 21 m. Following that investigation, diving operation and an inspection involving a Remotely Operated Vehicle (ROV) were conducted two weeks after the accident. However, both activities failed to obtain the result due to the unreachable location and water visibility. For those reasons, hydro-acoustical methods then were chosen to investigate the wreck and possible obstacle involved.

Multibeam Swath Bathymetry

A Reson Hydrobatmultibeam system was used in data acquisition. This system operates in a frequency of 160 kHz with total of 112 beams and 120° of swath width(Ths.org.uk, 2010). Some studies used this multibeam system for water quality modeling (Chen *et al*., 2017), fish migration (Xu *et al*., 2017), and underwater target detection (Manik *et al*., 2014).During data acquisition, the vessel was navigated and steered using Hypack navigation software. Thus, some waypoints of chronological events that had been pre-investigated previously were inputted to the software as guidance during the survey. Multibeam data was processed using a CARIS HIPS and SIPS 6 software to obtain the Digital Elevation Model (DEM) of bathymetry. A standard processing and data cleaning method was performed to remove the outliers.

Side-scan Sonar

A side-scan sonar system generally consists of a 'tow-fish' that is connected to the on-board receiver using a tow-cable. This 'tow-fish' is basically a sensor that emits acoustic signals, which then were received by a double transducer in port and starboard side. As a result, the resultant beam would cover each side transducer a narrow yet long section of the seafloor (fan-shaped lobe) (Lianantonakis & Petillot, 2007; Harrison *et al*., 2011).The slant range system used in side-scan sonar leads a geometrical distortion in across-track direction due to different compression of portrayed objects in far and near the nadir (Figure 2). Thus, an inaccurate interpretation of the object's geometry is ever-present. Object (target) height is generally calculated based on its shadow in the image (the area from D3 to D4 in Figure 2(b)). This is because of the loss of backscattered energy due to blocked by the object which directly facing the transducer.

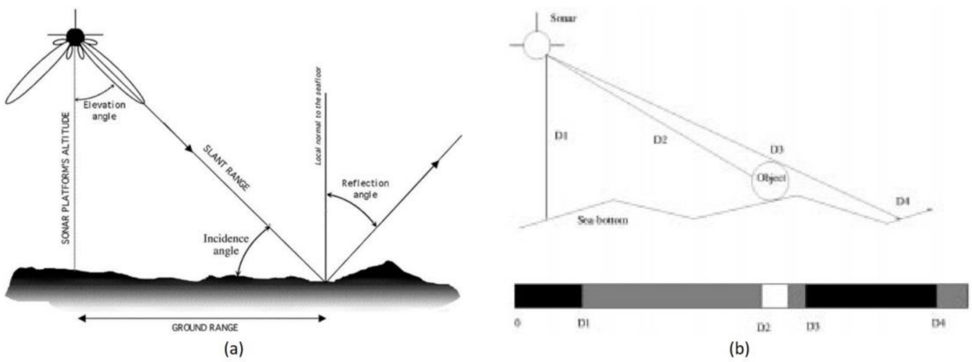


Figure 2.(a) Side-scan sonar signal propagation (Blondel, 2009), (b) Image construction (Daniel *et al*., 1998)

An Edgetech 4200 FS side-scan sonar system was used in this study to produce a high-resolution seafloor image. This side-scan sonar system operates in dual-frequency of 100/410 kHz, which can cover 500 meters (100 kHz) and 150 meters (410 kHz) side coverage of seafloor. With the spatial resolution of 2 – 8 cm (across-track) and 0.5 – 2.5 cm (along-track), this sonar system is adequate to be used in archaeological investigation. The use of this SSS system can be found in several studies such as wreck site monitoring (Bates *et al*., 2011), seafloor pockmarks investigation (Mueller, 2015), and seabed fluid flow (Jones *et al*., 2009). The same positioning system (A Coda Octopus F180 GPS and Inertial Motion Unit) for the multibeam system was used with a vessel offset from the GPS antenna to the towing point at the vessel bow. During the data acquisition, the SSS sensor (tow-fish) was towed in a maximum of 10 m (layback) behind the vessel to minimize the positioning accuracy due to the lack of accurate underwater positioning system (e.g. ultra-short baseline/USBL system). Particularly at the wreck location, the tow-fish was towed as closed as possible to the water surface since the topside of the wreck was only 5 meters below the water surface at the low tide. Sonar data was recorded simultaneously with the multibeam data during the survey. The raw data was then displayed and captured using Discover software. Object’s height and position can be obtained from the sonar image and examined in parallel of the multibeam data.

Slope Analysis

Slope is one of the derivation layers of bathymetry that could lead to prominent information and an effective method in revealing an underwater wreck. This is due to its capability to distinguish the wreck’s body with the surroundings. Micle *et al*., (2010) used this information to analyze the archaeological site in Romania. Firstly, a 3-by-3 low-pass filter was applied to the DEM imagery to remove small noises and smooth the image. After that, the Slope was created using Benthic Terrain Modeller (BTM) in ArcGIS from DEM that had been produced previously. Reclassification of DEM was carried out to group the slope into the wreck (Slope > 70^{o}) and non-wreck (Slope < 70^{o}) since the wreck will characterize a high sloping than surroundings.

Edge Detection of Wreck

Edge detection is one of the methods in image segmentation. Samiee & Rad (2008) stated that edge detection could be useful to detect an object and its boundaries in the image. Implemented in Matlab, there are several stages used in this study. Initially, the side-scan sonar image was converted to grayscale (black/white) image. Prior to edge detection, a median filter was applied to remove the speckles and noise in the sonar image as suggested by (Hayes & Ho, 2004). A median filter is a low-pass filter that will keep the edge pixels of the image; thus, important textural in the image will be maintained. A 5 x 5 window was used for the median filter since it has been proven as the most effective size for the filter (Febriawan *et al*., 2019; Wesselink *et al*., 2017).Afterward, a Sobel filter was used for edge detection. Sobel filter has been demonstrated to be used in side-scan sonar image segmentation as can be found in (Leros & Andreatos, 2016;Hayes & Ho, 2004; Brennan *et al*., 2012). It is explained in (Jensen, 2015) that Sobel filter is a non-linear edge enhancement (detector) that uses a 3 x 3 moving window to detect the edge of an object in the image.

RESULT AND DISCUSSION

Navigation tracking

The investigation survey was using MV. Wihan Sejahtera’s navigational data which was reproduced from the vessel’s AIS data as acquired from the local Vessel Traffic Service (VTS). Following the data, the vessel’s track known and be the main reference for the survey. As the survey boat was navigated through the line, the on-line multibeam and side-scan sonar displays were monitored in real-time and recorded the data. The important suspected objects were noted, which then can be examined further. The survey was then focused in the location of the MV Wihan wreck (Figure 3a) and run the lines several times with different directions to get the full-coverage imagery of the wreck (Figure 3b).

Underwater findings

The use of accurate positioning system and vessel closed towing system techniques have led to reliable results of underwater imaging resulted from multibeam and side-scan sonar. This was proven by several valuable results of possible causes along the vessel-recorded track previously. The several important findings that located along the track were summarized in five (5) underwater objects in the Table 1.

The fifth object found by side-scan sonar (Table 1) was suspected as the main cause of vessel collision. On 24 December 2015, it was found a spud pile at the location of 7° 10’ 28.89” S/ 112° 41’ 36.01” E (approximately 600 m from the fifth object coordinates) and then was recovered from the seabed (KNKT, 2015). It was reported that the vessel draft when departed was 6 meters below the water surface. Considering that the depth of the crash location is around 20 m, it means there was a water column clearance around 14 m in that location. The fifth object had dimension 14.9 m of height and 1.5 m of width, which was fitted with that information. In addition, the recovered spud pile had dimension 1.8 of diameter and there was damage in eyepatch and bent of 15 m from the top of the eyepatch (Figure 4). It was suspected that the cause of the damage was the collision with the vessel hull and resulting in a severe rip of the vessel hull.

In addition, the multibeam survey carried out in the wreck location produces a high-resolution digital elevation model (DEM) as can be seen in Figure 5. It can be noticed that the depth at wreck location is relatively flat with depth varies from 16 to 30 m. The wreck’s body was located only 3.8 m below the water surface. Albeit the wreck shape cannot be portrayed clearly, its shape (elevation) can be differentiated from the seabed surroundings. Thus in object detection, slope analysis is common to be used for DEM bathymetry. On the other hand, in the side-scan sonar imagery that does not contain depth information, the object detection is subject to image processing domain. Therefore, edge detection is more suitable to be used for side-scan sonar imagery.

Slope analysis and Edge detection

The experiment of slope analysis and image segmentation were applied to the wreck image (both DEM and side-scan sonar image) of MV Wihan Sejahtera. The slope result of DEM (figure 6(a)) indicates that the area of the wreck has a relatively low slope (flat area). The figure 6(a) also depicts that the wreck produces a high slope (approximately 70˚ to 86˚). Thus, classifying the image based on that degree of slope could reveal the boundary of the wreck. The classification process was using the classification tool in ArcGIS and the result is shown in Figure 6(b). The classified image, which contains wreck and non-wreck classes, depicts the wreck pronouncedly than the slope image produced previously. Although there are a few miss-classified pixels of seabed that classified as wrecks, overall, the wreck class indicates a similar result with the boundary in the slope image.

The slope feature resulted from DEM bathymetry could show a sufficient result to reveal the wreck shape and dimension. One of the causes of this is a flat area in the location led to a clear boundary than the surroundings. Although in archaeological fields, Micle *et al*., (2010) used the slope to investigate the potential location of the archaeological settlement, slope also has been proven as a good tool for object detection. The slope classification also shows a promising result since it can produce a near perfect of wreck shape and only minor miss-classification features on seabed. A combination of the slope feature and texture analysis of side-scan sonar imagery could be a promising input for machine learning classifiers for underwater and seabed classification. Unfortunately, the side-scan sonar

Figure 3.The survey was then focused in the location
Note. (a) Navigation tracking of MV Wihan Sejahtera, (b) Survey track line at the wreck location

Figure 4. A damaged eyepatch and spud pile

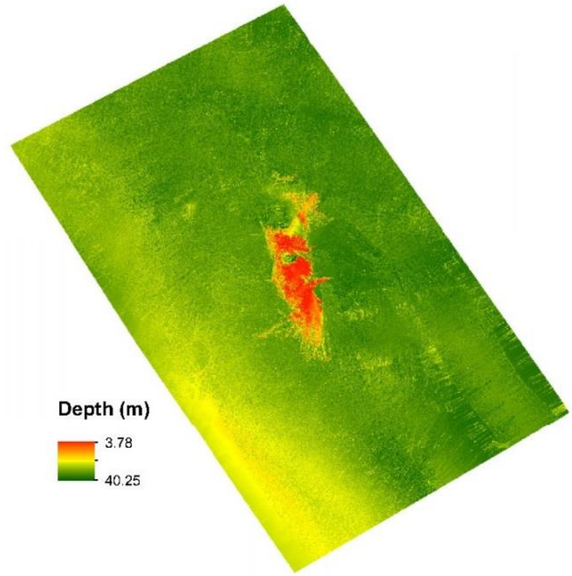


Figure 5. Digital elevation model (DEM) bathymetry of the wreck

image of the same location is unavailable, which only resulting in a partial image of the wreck (Figure 7) due to the shallow depth space between the tow-fish at the water surface and the topside of the wreck.

The edge detection method was used for segmenting the wreck image of MV Wihan Sejahtera. Initially, the purpose of investigation in the location above the wreck was to obtain the information of rips of the vessel's hull. Thus, it was expected that the sonar image could reveal that rips as the cause of the accident.

The sonar images (Figure 7) show that the wreck was skewed 40˚ to the starboard side of the vessel. This was resulting in starboard and hull sides of the vessel were embedded in the seabed and cannot be portrayed in the image. Consequently, visual examination and interpretation of the rips became not possible, though the wreck had been portrayed in detail in the sonar image. All of the vessel's parts are still completed meaning it sank smoothly without any crash with other hard objects. In the image, the vessel's bow and stern are located in half of the water column (dark side) and can be interpreted that its body lied in half of the depth in the location. Figure 8 depicts edge-detection results that consists of grayscale images, smoothed images, and edge detection images. Smoothed images (Figure 8 (b) & (e)) show that the objects of seabed and wreck are seamless with sharper in the object's boundaries. It also can be noticed that small speckles in the images have been removed. Hayes & Ho (2004)explained that side-scan sonar images contain clear noises (salt and pepper), which can lead to miss-detected of the edge of the vessel. Although Gao *et al*., (2010) argued that a combination of median filter and Sobel filter could not remove the noises in the common images effectively, the median filter also shows a good result applied to side-scan sonar image in this study. Sobel filter that was used for edge detection indicates that this filter worked well to detect the edge of the wreck (Figure (c) & (f)). The wreck's shape in the segmented images is also consistent with its shape in the sonar image. The grayscale images of side-scan sonar have a limitation of the existing rectangular grid, which should be removed for image processing purposes. This is resulting in some linear strips remain in the segmented images. In addition, thereare some miss-detected features in the results, which are probably caused by a high-saturated seafloor because of strong signal returns near the nadir. This also has been explained by Hamill *et al*. (2018) that in 8-bit quantization of the sonar image is not adequate enough to captivate the dynamic range of backscatter signal, particularly in the off-nadir area. Thus post-processing stages, which are detail explained in Blondel (2009), are compulsory in order to get a sufficient result of the sonar image for further analysis.

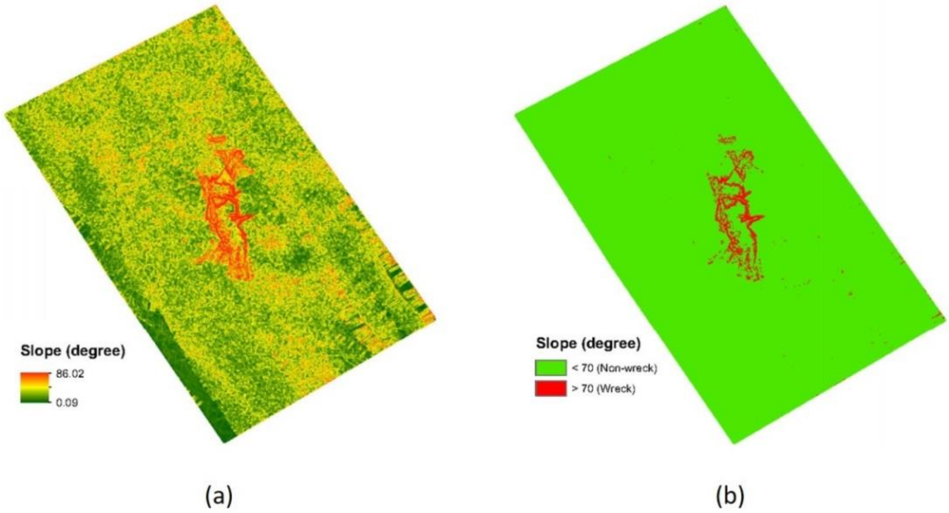


Figure 6. (a) Slope feature of the DEM bathymetry, (b) Result of slope classification

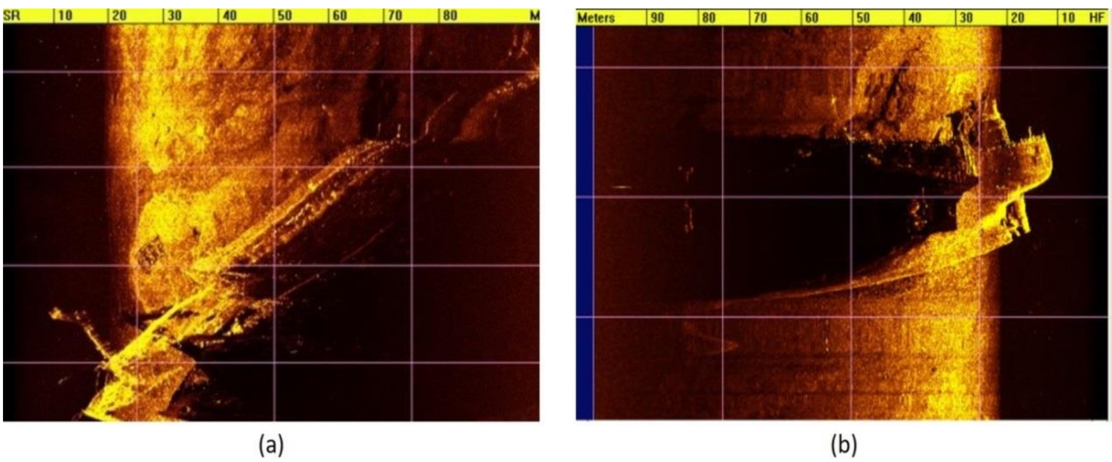
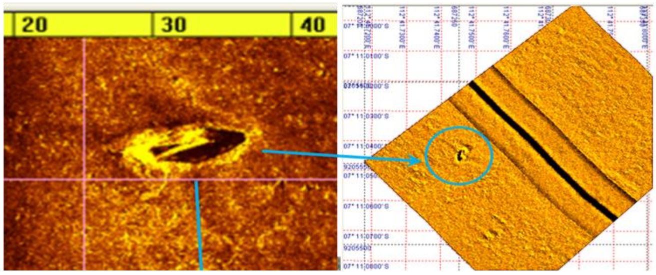
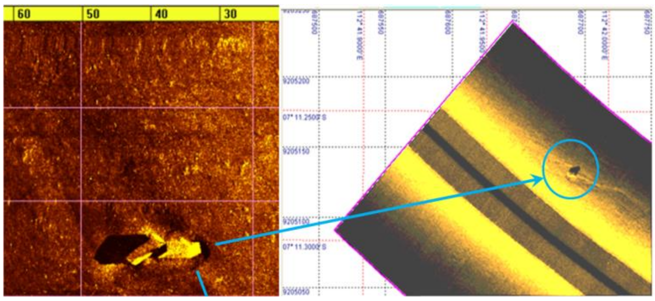
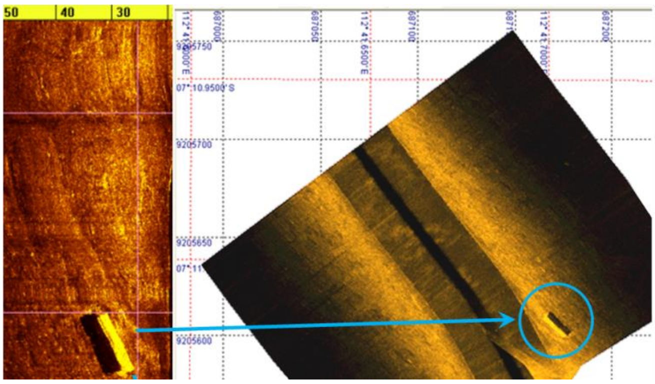
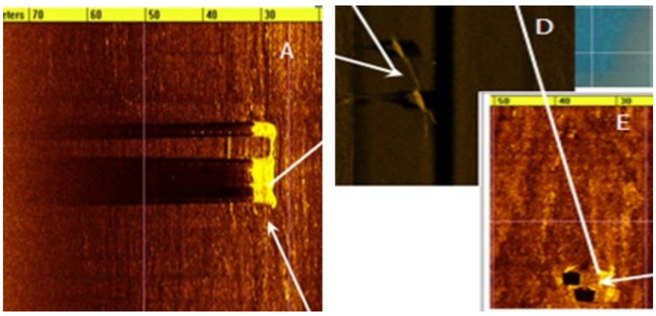
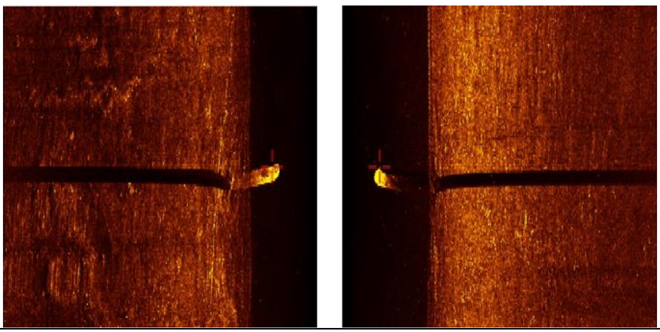


Figure 7. (a) Sonar image of the wreck showing the bow of the vessel, (b) Sonar image of the wreck showing the after end of the vessel

Table 1. List of underwater findings

No	Sonar Image	Coordinates	Size
1		7°11'0.3"S, 112°41'44.7"E Depth: 19 m	5m x 4m x 2m
2		7°11'16.2"S, 112°41'59.4"E Depth : 17 m	5m x 2m x 2m
3		7°11'15"S, 112°41'42.12"E Depth : 20 m	7m x 2m x 2m Suspected as a container
4		7°10'25"S, 112°41'17"E	length of 11 m with 7 m of connecting support
5		7°10'24.70"S, 112°41'16.82"E	14.9 m of height and 1.5 m of width

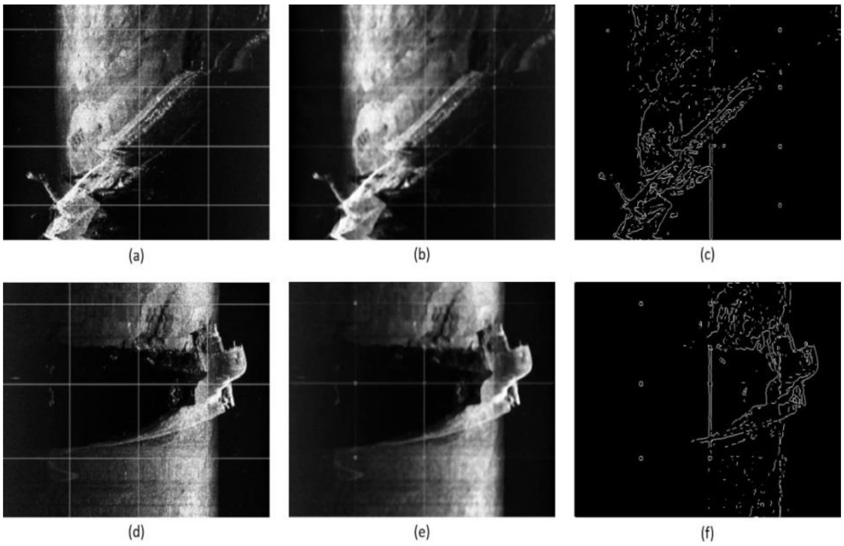


Figure 8. Result of edge-detection: (a) & (d) grayscale images of the wreck, (b) & (e) smoothed images of the grayscale images (a, b), (c) & (f) result of edge-detection

CONCLUSION

This study tried to describe the use of two hydro-acoustic survey techniques to investigate a vessel accident. Side-scan sonar and multibeam echosounder were used to produce high-resolution sonar imageries and digital elevation model (DEM) bathymetry. In addition, slope and edge-detection analysis also were examined for the wreck's shape detection. The results showed that several sonar images of the suspected underwater objects causing the accident could be portrayed clearly. One of those objects was confirmed as the cause of the accident. Slope feature with the values up to 70˚ also depicted a clear vessel wreck's shape with the surroundings. The sonar image of the wreck indicated that all parts of the vessel were still completed, though the rips as the cause of the accident could not be examined due to wreck position. However, the edge detection method using a Sobel filter demonstrated an expectant result to detect the wreck's shape. Future research would try to examine the use of machine learning classifiers using morphometric and textural features for underwater object detection and seabed classification.

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