CLASSIFICATION OF MULTIBEAM SNIPPETS DATA USING STATISTICAL ANALYSIS METHOD

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CLASSIFICATION OF MULTIBEAM SNIPPETS DATA USING STATISTICAL ANALYSIS METHOD

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requirements for the award of the degree of
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I humbly dedicate this thesis to

My Grandmother

Wong Ksuin

My Beloved Parent

Lau Mun Hong & Hui Mew Ying

My Family Members

Lau Sook Fun

Lau Sook Yen

Lau Kum Fai

My Loved One

Lim Li Xin

Buddies & Friends

Thanks for your support and encouragement.

Thanks for the blessing and best wishes.

Thanks for the sacrifice and patience.

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ABSTRACT

The multibeam snippets data, an acoustic backscatter data acquired by the multibeam sonar systems, carries important information about the seafloor and its physical properties, thus aid in seafloor classification. This acoustic backscatter strength is highly dependent of incidence angle due to different mechanism of scattering with different angular domains. Therefore, it is necessary to perform certain corrections for the backscatter data before producing the hydrographic plan. This is solved with the radiometric correction using CARIS HIPS & SIPS 7.0 software and geometric correction using Matlab programming. Radiometric correction removed the Time Varied Gain from the data while geometric correction corrected the data for local bottom slope, seafloor insonified area and angular dependency. The seafloor can be classified using the produced distribution histogram of the desired study area. It is found that the snippets intensities estimated from the mean of snippets intensities provide an accurate measurement of the actual intensities strength of the seafloor and play an important role in correcting the angular dependency of the data. Besides that, the Gamma distribution model is found to be fitting well with the distribution of snippets intensities. The parameters of the Gamma distribution model, the scale and shape parameters are found to be dependent on the incidence angles of data. Furthermore, the Kolmogorov-Smirnoff test was carried out to access the fitting of other statistical distribution models such as the Rayleigh and Log-normal distribution models in fitting with the distribution of snippets intensities. It is shown that the Rayleigh and the Log-normal distribution models followed only with the head of the distribution of the experimental data but not towards the tail of experimental distribution. Further experiment on comparing the backscattering characteristics of snippets data that were collected from different types of seafloor habitats is recommended for future research.

ABSTRAK

Data pemerum gema berbilang alur *snippets*, suatu data sebaran akustik yang diperolehi dengan sistem pemerum gema berbilang alur, membawa maklumat penting mengenai dasar laut dan sifat-sifat fizikalnya serta membantu dalam pengklasifikasian dasar laut. Kekuatan sebaran balik akustik ini amat bergantung kepada sudut tuju sebaran disebabkan oleh mekanisme sebaran yang berbeza dengan domain yang berlainan sudut. Oleh itu, pembetulan tertentu perlu dilakukan bagi data sebaran balik sebelum menghasilkan pelan hidrografi. Ini dapat diselesaikan dengan pembetulan radiometrik menggunakan perisian *CARIS HIPS & SIPS 7.0* dan pembetulan geometrik menggunakan pengaturcaraan *Matlab*. Pembetulan radiometrik membetulkan data untuk *Time Varied Gain* manakala pembetulan geometrik membetulkan data untuk kecerunan dasar laut, keluasan kawasan dan pergantungan kepada sudut. Dasar laut boleh diklasifikasikan dengan menggunakan histogram taburan untuk kawasan kajian tersebut. Adalah didapati bahawa keamatan *snippets* yang dianggarkan daripada min keamatan *snippets* menyediakan suatu ukuran tepat kekuatan keamatan sebenar dasar laut dan memainkan peranan penting dalam membetulkan pergantungan sudut data. Selain itu, model taburan *Gamma* didapati sesuai dengan taburan keamatan *snippets*. Parameter model taburan *Gamma*, iaitu parameter skala dan bentuk didapati bergantung kepada sudut tuju data. Tambahan pula, ujian *Kolmogorov-Smirnoff* telah dijalankan untuk mengakses penyesuaian model taburan statistik seperti *Rayleigh* dan *Log-normal* dengan taburan keamatan *snippets*. Keputusan menunjukkan bahawa taburan model *Rayleigh* dan *Log-normal* hanya mengikuti taburan data eksperimen di permulaan tetapi tidak ke akhir taburan eksperimen. Eksperimen selanjutnya bagi perbandingan ciri-ciri sebaran data *snippets* dari pelbagai dasar laut dicadangkan untuk kajian pada masa hadapan.

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LIST OF ABRREVIATIONS

ASCII	-	American Standard Code for Information Interchange
AUV		Autonomous Operated Vehicle
B.A	-	Backscatter Area
BASE	-	Bathymetry with Associated Statistical Error
BITE	-	Built-In Test Environment
BS	-	Backscatter Coefficient
BTS	-	Bottom Target Strength
CARIS	-	Computer Aided Resource Information System
CDF	-	Cumulative Distribution Functions
CLT	-	Central Limit Theorem
CUBE	-	Combined Uncertainty and Bathymetric Estimator
DB	-	Decibel
DEM	-	Digital Elevation Model
DNC	-	Digital Nautical Chart
DpTPU	-	Depth Error Estimate
EEZ	-	Exclusive Economic Zone
EL	-	Echo Level
ENC	-	Electronic Navigation Chart
GIS	-	Geographic Information System
GLCM	-	Grey Level Co-Occurrence Matrix
HDCS	-	Hydrographic Data Cleaning System
HIPS	-	Hydrographic Information System
HVF	-	HIPS Vessel File
Hz	-	Hertz
HzTPU	-	Horizontal Error Estimate

IHO	-	International Hydrographic Organization
IL	-	Acoustic Intensity
KS	-	Kolmogorov-Smirnoff
MBES	-	Multibeam Echo Sounder
MBSS	-	Multibeam Side Scan
MRU	-	Motion Reference Unit
MSP	-	Method of Small Perturbation
NPD	-	Norwegian Petroleum Directorate
PDF	-	Probability Density Distributions
PPT	-	Parts Per Thousand
RMS	-	Root Mean Square
ROV	-	Remotely Operated Vehicles
RP	-	Reference Point
SBES	-	Single Beam Echo Sounder
SCS	-	Seafloor Classification Systems
SIPS	-	Sonar Image Processing System
SNIPPETS	-	Seafloor Backscatter Envelopes
Std Dev	-	Standard Deviation
SSA	-	Small Slope Approximation
TL	-	Transmission Loss
TPU	-	Total Propagation Uncertainty
TVG	-	Time Varied Gain
XTF	-	Extended Triton Format

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hydrographic surveying can be defined as a science of measuring and depicting the parameters and characteristics of the seabed to define the surface of the seabed, the geographical relationship of the seabed with the land mass and dynamical features of the sea (International Hydrographic Organization, 2005). For the purpose and needs for surveying and navigation, these parameters consist of depth or bathymetric data, the pattern and morphology of the seabed, velocity and direction of currents, tides, wave and the position of underwater objects (International Hydrographic Organization, 2005).

Until the Second World War, almost all of bathymetric surveys were made by lead line. The introduction of single beam echo sounder (SBES) after the world war has replaced the conventional lead line techniques. The SBES collects bathymetric data by the measurement of the travel time interval of the returned acoustic signal (Mayer *et al.*, 2007) and provides better accuracy than the lead line techniques. In 1980s, Multibeam Echo Sounder (MBES) or Multibeam Sonar System has been introduced in hydrographic surveying as a tool for bathymetric data collection. Figure 1.1 shows the principle of single beam echo sounder whilst Figure 1.2 shows the principle of multibeam echo sounder.

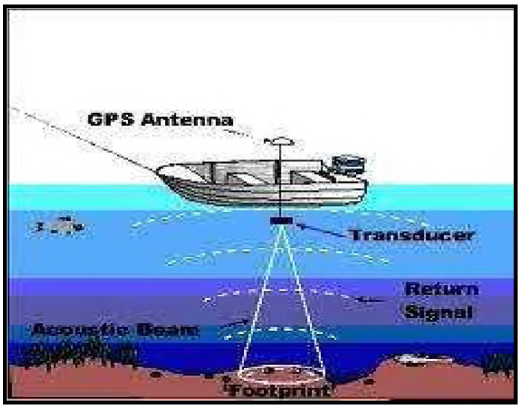

Figure 1.1: Principle of single beam echo sounder

(Source: http://www.ozcoasts.gov.au/glossary/def_s-t.jsp)

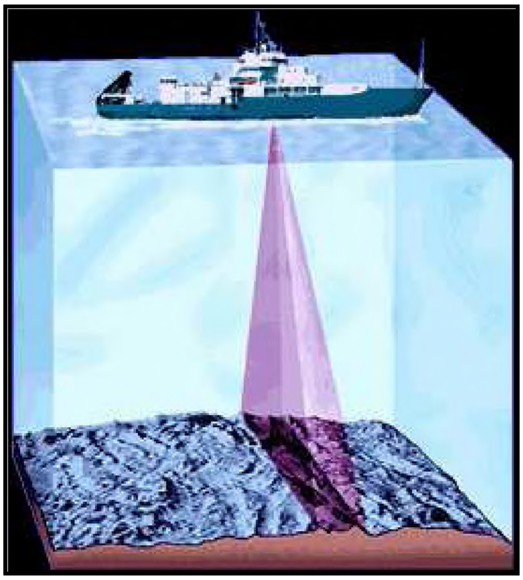

Figure 1.2: Principle of multibeam echo sounder

(Source: http://divediscover.whoi.edu/tools/sonar-multibeam.html)

Development of maritime activities in Malaysia has increased rapidly. Therefore, the data from hydrographic surveying nowadays is widely used not only for nautical charting, but also for other applications such as marine engineering, pipe or cable laying and inspection, sedimentation studies, ocean habitats studies as well as maritime boundary determination.

1.1.1 Acoustic Remote Sensing Technique in Seafloor Study

Towards the development in the exploration and exploitation, the ocean has become a powerful and commercial interested subject among the industries. Marine activities whether in the field of oil & gas exploration, marine geology and etc., need more and more seabed recognition tools and methods. Acoustic remote sensing techniques are one of the most cost-effective methods of resource mapping, particularly in the coastal zone. Seabed mapping and monitoring using acoustic remote sensing techniques has proven to be a useful tool in contemporary marine resource management particularly in turbid and deep water areas, where aerial and satellite remote sensing based on measuring the electromagnetic spectra is of limited use (Caruthers, 1977). The applications of acoustic remote sensing technique in seafloor study include measurements such as: a.) Bathymetry, which provides quantitative information on the relief; b.) Acoustic imaging, which is most often used in a qualitative sense for geomorphology and for feature detection of obstacle avoidance; c.) Acoustic bottom loss which is related to the physical properties of the substrate (de Moustier and Matsumoto, 1993).

Backscatter data or better known as the acoustic intensity of the seafloor is one of the by-products of MBES systems. The power of the received signal is analysed and compared with the transmitted signal and corrected for parameters such as incidence angle, attenuation and etc. Some processing algorithms record the full waveform for each footprint, piece the sample string back together, and analyse the resulting wave trend in a manner similar to side scan. This approach can yield backscatter data with higher resolution (smaller pixel size) than the bathymetry data (Daniel *et al.*, 1999). In the measurement of backscatter data, the data are logged simultaneously with bathymetric data, which will permit precise co-registration of the backscatter with the multibeam data set, resulting the positional accuracy of the backscatter to be better compared to the traditional side scan image (FUGRO, 2005)

Backscatter data carries important information about the seafloor and its physical properties (Fonseca and Calder, 2005). This information may provide valuable data to aid in seafloor classification and important auxiliary information for a bathymetric survey. Acoustic imagery of the seafloor, generated from either multibeam or towed side scan sonar system, represents the received acoustic backscatter intensities. These acoustic intensities depend on the scattering strength of the seafloor, distribution of scatterers, degree of bottom penetration and sub-bottom volume scattering, and ensonification angle (Whitmore, 2003). Acoustic backscatter imagery is used in a diverse set of applications and disciplines ranging from geological mapping to the detection of manmade objects on the seafloor. As such, acoustic backscatter imagery has many naval applications that include obstacle avoidance, characterization of the type of seafloor for engineering purposes, mine detection and parameterization of the seafloor for acoustic propagation modelling (Etter, 2003).

Currently, there are two approaches in the collection of backscatter data using multibeam system; the Multibeam Side Scan (MBSS) and Seafloor Backscatter Envelopes (Snippets). Multibeam Side Scan and Snippets can display a representation of the seafloor using the principle of acoustic imaging.

1.1.1.1 Multibeam Side Scan (MBSS)

Multibeam Side Scan is acquired by forming a large beam on either side of the sonar head. Time series data is sampled across these beams by summing all of returns from any given time to a pixel (quoted from webpage: http://www.fugro-pelagos.com/papers/Backscatter_GIS.doc.). The result of the Multibeam Side Scan imaging is a mosaic covering the seafloor. Assuming the lines have been run appropriately, the imaging should provide 100% coverage and it may be that the intensities information covers more than the bathymetry unless the beams have been invalidated for accuracy reasons (International Hydrographic Organization, 2005). It is likely that the extra intensities information will not be used since it does not have depth information associated with it, but it remains available. The drawbacks of the Multibeam Side Scan is that potentially useful spatial information is discarded in the process of reducing the intensities time series surrounding the bottom detect of each beam to a single value. Figure 1.3 shows the multibeam side scan sonar imagery.

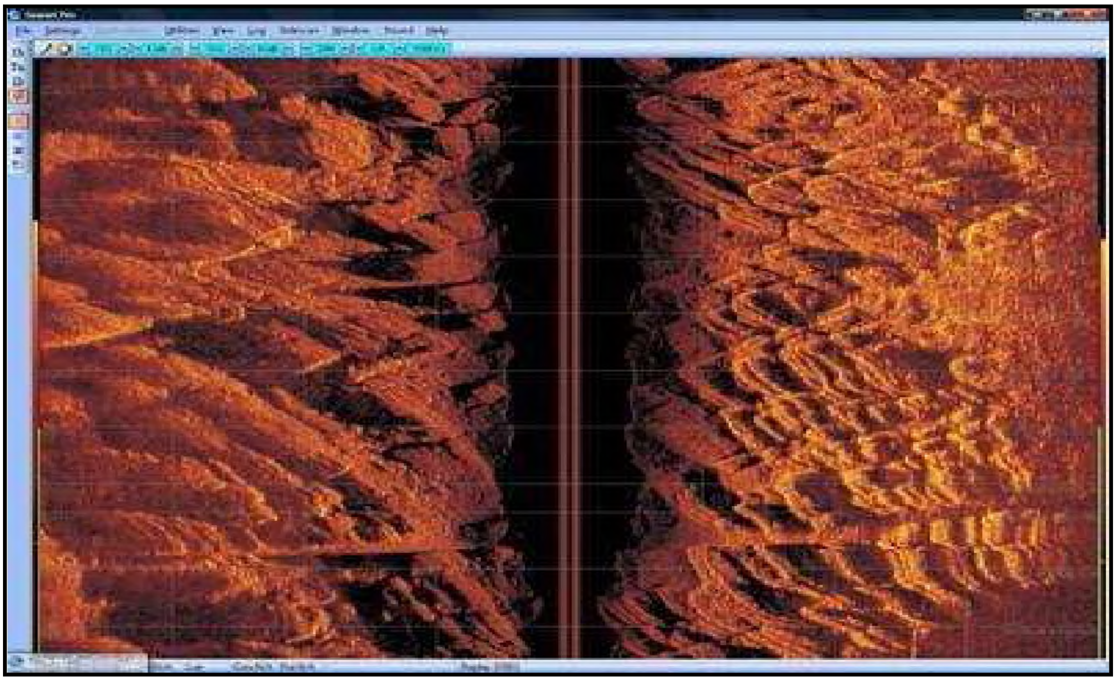

Figure 1.3: Multibeam Side Scan Sonar Imagery
(Source: http://halmapr.com/news/tritech/category/news/page/4/)

1.1.1.2 Seafloor Backscatter Envelopes (Snippets)

The multibeam seafloor backscatter envelopes or better known as multibeam snippets data, are acquired by sampling an individual time series for each beam in the multibeam system. Sampling only occurs in the region of the bottom detect rather than throughout the water column (time-arc) (quoted from webpage: http://www.fugropelagos.com/papers/newdevinmulitbeambackscatter/tgpibackscatter.htm). These samples are assigned as backscatter return for their respective individual beam footprints. As a result, the signal-to-noise ratio of the backscatter is greatly improved. Figure 1.4 shows the multibeam snippets imagery whilst Figure 1.5 shows the derivation of multibeam backscatter imagery.

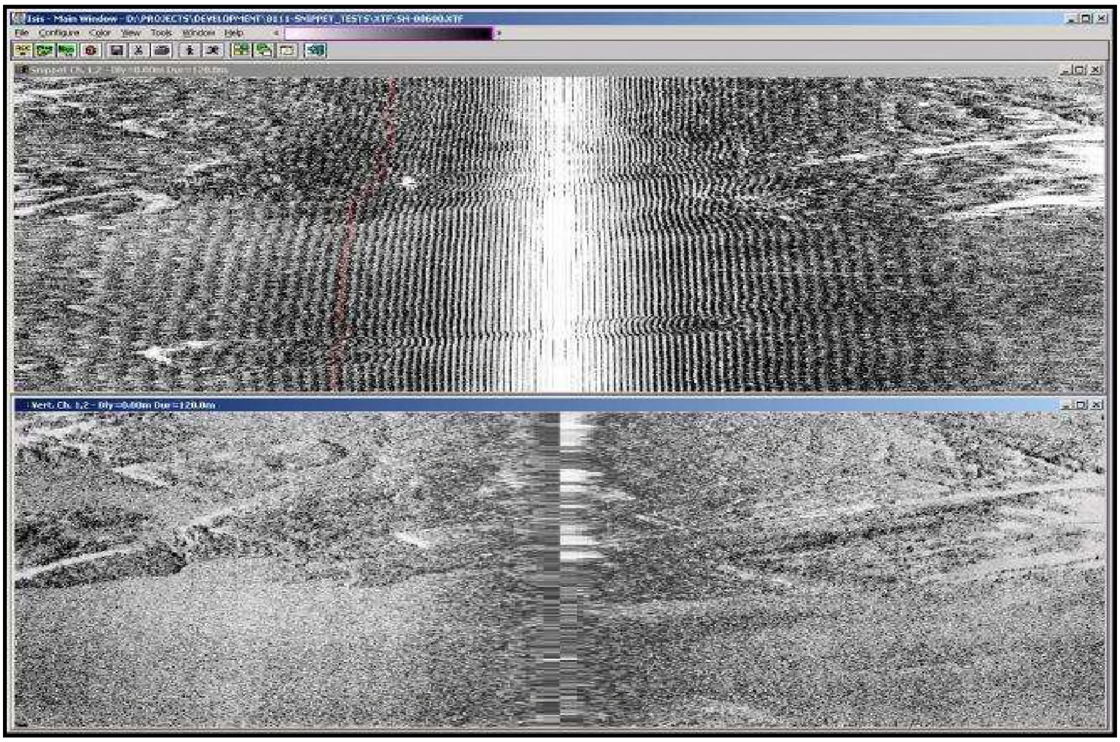

Figure 1.4: Multibeam snippets imagery
(Source:http://www.fugropelagos.com/papers/newdevinmulitbeambackscatter/tgpibackscatter.htm)

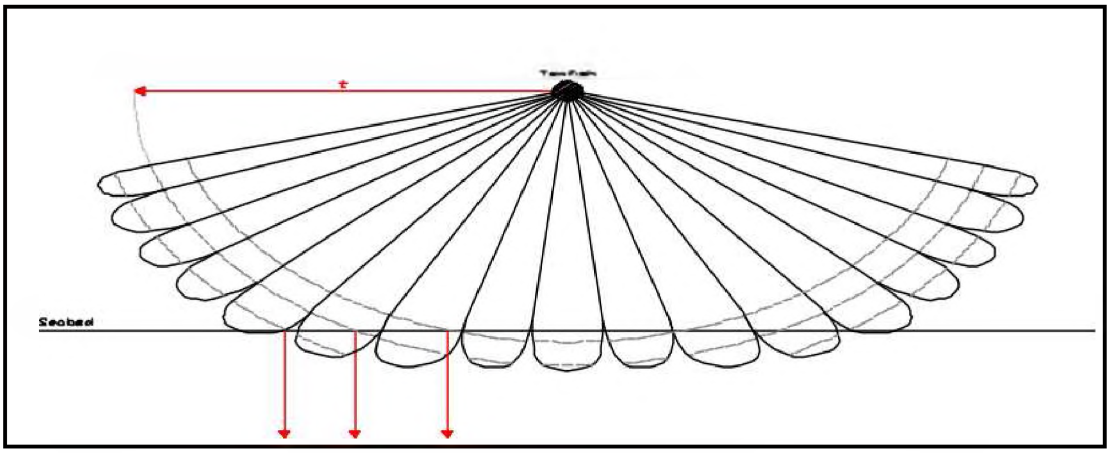

Figure 1.5: Derivation of multibeam backscatter imagery
(Source:http://www.fugropelagos.com/papers/newdevinmulitbeambackscatter/tgpibackscatter.htm)

As the snippets data act as an individual time series that directly associated with a portion of the bathymetric profile, therefore it is much easier to correct for slant range. When properly processed, multibeam snippets data can provide a view of seafloor geology and geomorphology at resolutions as little as a few decimetres and applicable in operations such as quantitative estimation of sediment transport in large-scale sediment waves and style of seafloor mass-wasting. In addition, the imagery potentially provides a means of quantitative classification of seafloor lithology, allowing the ability to examine spatial distributions of seabed sediment type without resorting to subjective estimation or prohibitively expensive bottom-sampling programs.

Provisions of snippets information are akin to the output of side scan sonar system and produce a representation of the seafloor in terms of the returned intensities echoes. The significant difference between the output of snippets information and side scan sonar system is that the multibeam echo sounder system is measuring the depth concurrently with the snippets information and this allows for a more sophisticated level of display. The depth data, when combined with beam angle, effectively gives the position on the seafloor to which the snippets information relate and therefore provide a true geometric correction of the backscatter image. Since this is in fact not the case, there will be distortions on the side scan sonar image. For this research, snippets data are collected and processed.

1.1.2 Correcting the Multibeam Snippets Data

The snippets signal received by multibeam sonar systems can be influenced by various parameters, which can be categorized into system settings (e.g. power, gain, pulse length), acoustic propagation conditions (e.g. absorption and spreading loss), beam geometry (e.g. range, incident angle, footprint size) and seafloor properties (seafloor roughness, acoustic properties). It is important that the received snippets signal is fully corrected so that it is invariant to system settings, propagation conditions and beam geometry so that changes in the snippets signal can be attributed to changes in the seafloor properties, and thus, be used to derive information about the substrate and geomorphology of the seabed (Gavrilov, 2005). More details are discussed in Chapter 3 and Chapter 4.

1.1.3 Statistical Analysis of Multibeam Snippets Data in Shallow Water

The statistical distributions of snippets values have been identified as a potential characteristic for classifying the seafloor. Exploiting the variation in multibeam backscatter measurements for seafloor classification has been achieved through probability density distributions (PDF) (Stewart *et al.,* 1994). In simplified terms, a weak return signal (low amplitude) indicates a soft bottom substrate and a strong return signal (high amplitude) indicates a hard bottom substrate (Gustav, 2008).

1.2 Problem Statements

Before a backscatter map can be made use, the backscatter data must be geographically registered using the collected bathymetric profile which accounts for full orientation and refraction. It is important to apply the radiometric correction to the backscatter data on a ping-by-ping basis for variables such as transmission power and receiver gain in order to turn them back to the "pure condition", which means the data are invariant to system settings.

Both system settings and acoustic propagation conditions are easily corrected for, however, artefacts (angular dependency) in multibeam backscatter images due to beam geometry are hard to remove. In particular, the angular dependency of multibeam backscatter strength can be persistent in multibeam backscatter images, characterized by a stronger return at vertical incident angles, known as 'nadir striping' (Siwabessy and Gavrilov, 2004). Attempts made at correcting through theoretical models, which are usually based on Lambertian law, seem to be inadequate especially for the modern multibeam sonar systems currently used for shallow water work (Siwabessy and Gavrilov, 2004). Furthermore, there are no universal models for angular backscatter correction suitable for every seabed type. Therefore, geometric corrections play an important role in resolving this problem. This included using the right method to remove the angular dependency from the data.

Middleton (1999) theoretically stated that the statistical distribution of the backscatter intensities should follow a gamma distribution model. However, recent studies have noted a non-Rayleigh character of backscatter statistics for shallow water seabed and suggested different models, such as Rayleigh mixture distribution (Gallaudet and de Moustier , 2003; Hellequin *et al.*, 2003; Lyons and Abraham, 1999; Abraham, 1997 and Dunlop, 1997) and log-normal distribution models (Trevorrow, 2004; Stanic and Kennedy, 1992 and Gensane, 1989). Therefore, it is important to determine the distribution model that best fitting with the distribution of the backscatter intensities.

1.3 Objectives

In this research, the objectives are specified as follows:

1.) To perform geometric and radiometric correction for multibeam snippets data.

2.) To perform seafloor classification with statistical analysis method using multibeam snippets data.

3.) Assessment of the statistical distribution models in fitting with multibeam snippets data.

1.4 Scope of Study

The scopes of this study are described as follows:

i. Study and hands-on practical on RESON SeaBat 8124 multibeam sonar system.
ii. Multibeam snippets data collection.
iii. Processing of multibeam snippets data.
iv. Studies on seafloor classification using statistical analysis method on measured multibeam snippets data.
v. Study area - for this research, data collection was carried out in shallow coastal waters with 500m x 500m coverage that located at Lido Beach, Johor Bahru, Malaysia (Figure 1.6).

Figure 1.6: Study area

1.5 Significance of Study

The use of acoustic remote sensing techniques in seabed mapping and monitoring has proven to be a useful tool in contemporary marine resource management (Kenny *et al.*, 2003), where aerial and satellite remote sensing based on the measurement of electromagnetic spectra is of limited use (Caruthers, 1977; Pickrill and Todd, 2003).

Seafloor acoustic response can be linked to sea-floor roughness produced by features such as ripples, benthic reworking and to physical properties of the surficial sediments (texture, dewatering, compaction, acoustic impedance, density, porosity, velocity). These properties are closely related, for example acoustic impedance is a function of velocity and density, which in turn depends on other properties such as compaction and porosity. It is an important development of acoustic remote sensing technique in marine science (Qiu-Hua Tang *et al.,* 2005).

The integration of bathymetry and backscatter information has led to a revolution and larger potential in our understanding of seabed features, sedimentary processes and seafloor studies. For this purpose, more research should be conducted. (Hughes Clarke *et al.,* 1997b; Mayer *et al.,* 1997b; Baker *et al.,* 1998 and Mayer *et al.,* 1999).

1.6 Thesis Layout

This thesis is divided into 7 chapters with details as stated below:

1) Chapter 1 mainly introduced the background of the study and to put the work in context.
2) Chapter 2 gave some key elements of relevant theory and a review of literature in the field of multibeam acoustic backscattering thus acoustic seafloor classification.
3) Chapter 3 presented the necessary steps in the measurement of multibeam snippets data.
4) Chapter 4 is the focus of Objective 1, where the radiometric and geometric correction of measured multibeam snippets data is discussed.

5) Chapter 5 is the focus of Objective 2 which devoted to the method of classification the seafloor using statistical analysis method.
6) Chapter 6 is the focus of Objective 3 which demonstrated and assessed the statistical variations of multibeam snippets data.
7) Thesis is ended with Chapter 7 which shows some discussion of the key findings and makes recommendations for future work in this research area.

1.7 Contributions of Research

In this research, the multibeam snippets data, which is one of the latest by-products of the multibeam system, is being explored for its usage in the study of seafloor classification. The RESON SeaBat 8124 multibeam sonar system is being upgraded and explored to generate and collect the multibeam snippets data. Other studies, such as Bentrem *et al.* (2006) and Houziaux *et al.* (2007) have used a side scan like approach to maximize the resolution of backscatter intensity produced by multibeam sonar systems. However, implementation of such an approach is not trivial because it requires adequate corrections for the backscatter data and beam pattern. Besides that, various tests and experiments have been carried out for the assessment of the statistical variations of the multibeam snippets data with the distribution models as stated theoretically by other researchers. As a result, this research aimed to give a better exploration of the acoustic backscattering technology, especially in the study of seafloor classification. Overall methodology of this study are presented in Appendix A.

1.8 Summary

This chapter briefly described the background of the study, providing a general view towards the acoustic remote sensing technique in seafloor study. These included discussion about the backscatter data and the necessary corrections for the data before a seafloor map can be produced with it.

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