

SATELLITE-DERIVED BATHYMETRY FOR SHALLOW WATER  
HYDROGRAPHIC MAPPING

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## DEDICATION

*To Allah Subhanahu Wa ta'ala, for the continuous strength. Physically and mentally.*

*To my parents, for giving me so much to be grateful for.*

*To my beloved wife, for endless supports and will always be there for me.*

*To my children, for aspirations and prayers. Indeed, this success story ain't easy.*

*May today's success be the beginning of your tomorrow achievements!*

*To the memories, for the hard times which made me much more determined to keep  
working hard.*

*To myself, for keep reminding me to be strong. Undeniably, I have fallen a lot along  
the journey.*

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## **ABSTRACT**

Satellite-Derived Bathymetry (SDB), a new method which derives bathymetric data from multi-spectral satellite imagery, has yet to be recognised as a new acquisition method for shallow water hydrographic survey mapping. Currently, SDB has received substantial attention from researchers worldwide, but most of the studies primarily focused on remote sensing environments. The questions about precision and accuracy are always the subject of interest in the surveying field but went unreported in most of the studies. Hence, this study aims to develop an improved SDB algorithm model which is capable of delivering better accuracy for shallow water hydrographic survey mapping application in a tropical environment. High resolution multi-spectral satellite imageries from the Sentinel-2A, Pleiades and WorldView-2 of Tawau Port, Sabah and Pulau Kuraman, Labuan were derived. Both places have diverse seabed topography parameters. A conceptual model of Multi-Layer Optimisation Technique (M-LOT) was developed based on Stumpf derivation model. Accuracy assessment of M-LOT was carried out against derivation models of Lyzenga and Stumpf. Two types of accuracy assessment were involved: Statistical Assessment and International Hydrographic Organization (IHO) Survey Standard evaluation. The findings showed M-LOT model managed to achieve up to 1.800m and 1.854m Standard Deviation (SD) accuracy for Tawau Port and Pulau Kuraman respectively. In addition, M-LOT has shown a better derivation compared to Stumpf's, where a total of 13.1% more depth samples meeting the IHO minimum standard for Tawau Port. Furthermore, M-LOT has generated an extensive increment up to 46.1% depths samples meeting the IHO minimum standard for Pulau Kuraman. In conclusion, M-LOT has significantly shown improved accuracy compared to Stumpf, which can offer a solution for SDB method in shallow-water hydrographic survey mapping application.

## ABSTRAK

Batimetri Penghasilan Satelit (SDB), kaedah baru yang menghasilkan data batimetri dari imej satelit pelbagai spektral masih belum lagi diiktiraf sebagai kaedah baru untuk pemetaan pengukuran hidrografi di perairan cetek. Pada masa ini, SDB telah menarik perhatian ramai penyelidik dari seluruh dunia namun kebanyakan kajian memberi keutamaan dalam bidang penginderaan jarak jauh. Persoalan berkaitan ketepatan dan kejituan sentiasa menjadi perkara utama dalam bidang pengukuran, tetapi tiada pelaporan mengenainya dalam kebanyakan kajian. Oleh itu, kajian ini bertujuan untuk membangunkan model algoritma SDB yang mampu menghasilkan ketepatan yang lebih baik khususnya bagi aplikasi pemetaan pengukuran hidrografi kawasan cetek untuk persekitaran tropika. Imej-imej satelit pelbagai spektral beresolusi tinggi dari Sentinel-2A, Pleiades dan WorldView-2 bagi kawasan Pelabuhan Tawau, Sabah dan Pulau Kuraman, Labuan telah dihasilkan. Kedua-dua kawasan tersebut mempunyai parameter topografi dasar laut yang berbeza. Model konsep Teknik Pengoptimuman Pelbagai Lapisan (M-LOT) dibangunkan berasaskan model penghasilan Stumpf. Penilaian ketepatan M-LOT telah dilaksanakan dengan model Lyzenga dan Stumpf. Dua jenis penilaian ketepatan telah digunakan; Penilaian Statistik dan evaluasi Piawaian Pengukuran Pertubuhan Hidrografi Antarabangsa (IHO). Dapatan ini menunjukkan model M-LOT berjaya menghasilkan ketepatan 1.800m dan 1.854m sisihan piawai untuk Pelabuhan Tawau dan Pulau Kuraman. Di samping itu, M-LOT telah menunjukkan penghasilan yang lebih baik berbanding Stumpf di mana penambahan sebanyak 13.1% sampel kedalaman berjaya mencapai piawaian minimum IHO bagi kawasan Pelabuhan Tawau. Tambahan pula, M-LOT telah menghasilkan peningkatan yang lebih ketara iaitu sebanyak 46.1% sampel kedalaman mencapai piawaian minimum IHO bagi kawasan Pulau Kuraman. Kesimpulannya, M-LOT telah menghasilkan ketepatan yang lebih baik berbanding Stumpf dan mampu menawarkan penyelesaian bagi kaedah SDB untuk aplikasi pemetaan pengukuran hidrografi kawasan cetek.

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## LIST OF ABBREVIATIONS

CARIS	-	Computer Aided Resource Information System
cm	-	centimetre
DOP	-	Depth of Penetration
DSMM	-	Department of Survey and Mapping Malaysia
EMR	-	Electromagnetic Spectrum
ENC	-	Electronic Navigation Chart
ESA	-	European Space Agency
GIS	-	Geographic Information Systems
HR	-	High Resolution
IHB	-	International Hydrographic Bureau
IHO	-	International Hydrographic Organization
IMO	-	International Maritime Organization
km	-	Kilometre
LADS	-	Laser Airborne Depth Sounder
LAT	-	Lowest Astronomical Tide
LiDAR	-	Light Detection And Ranging
LTE	-	Low Tide Elevation
LUT	-	Look-Up Tables
LWL	-	Low Water Line
MATLAB	-	Matrix Laboratory
m	-	metre
mm	-	millimetre
MBES	-	Multibeam Echo Sounder System
MRSA	-	Malaysia Remote Sensing Agency

MSI	-	Multi-Spectral Image
NASA	-	National Aeronautics and Space Administration
NHC	-	National Hydrographic Centre
NIR	-	Near-Infrared
nm	-	nautical mile
NOAA	-	National Oceanic and Atmospheric Administration
OLI	-	Operational Land Imager
RMSE	-	Root Mean Square Error
SBES	-	Single Beam Echo Sounder System
SD	-	Standard Deviation
SDB	-	Satellite-Derived Bathymetry
SHOALS	-	Scanning Hydrographic Operational Airborne LiDAR Survey
SOLAS	-	International Convention for the Safety of Life at Sea
SONAR	-	Sound Navigation and Ranging
SPOT	-	<i>Satellite Pour l'Observation de la Terre</i>
TIRS	-	Thermal Infrared Sensor
ToA	-	Top of Atmosphere
TS	-	Territorial Sea
TSB	-	Territorial-Sea Baseline
TVU	-	Total Vertical Uncertainty
UNCLOS	-	United Nation Convention on the Law of the Sea
VHR	-	Very High Resolution
V-NIR	-	Visible and Near-Infrared
WGS 84	-	World Geodetic System 1984

## LIST OF SYMBOLS

$A_d$	-	Bottom upwelling radiance
$a_i$	-	Constant coefficients
$b_i$	-	Slope resulting from a regression of band $i$
$DN_i$	-	Pixel digital number for band $i$
$g$	-	Two-way attenuation coefficient
$K_i$	-	Absolute radiometric calibration
$L_b$	-	Bottom radiance
$L_p$	-	Atmospheric path radiance
$L_s$	-	Specular radiance
$L_t$	-	Total upwelling radiance
$L_v$	-	Subsurface volumetric radiance
$L_\infty$	-	Optically-deep water radiance
$min_{NIR}$	-	Minimum near-infrared value
$n$	-	Total number of the samples
$R^2$	-	Coefficient of determination value
$R'_i$	-	Sun glint and atmosphere corrected image for band $i$
$R_i$	-	Uncorrected image (radiance) of band $i$
$R_{NIR}$	-	Near-infrared radiance
$x_i$	-	Real depth (reference depth)
$\hat{x}_i$	-	Derived depth (predicted depth)

$\bar{z}_i$	-	Mean of depth residual sample
$z$	-	Depth
$z_i$	-	Depth residual sample
$\Delta\lambda_i$	-	Effective band (band i)

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# CHAPTER 1

## INTRODUCTION

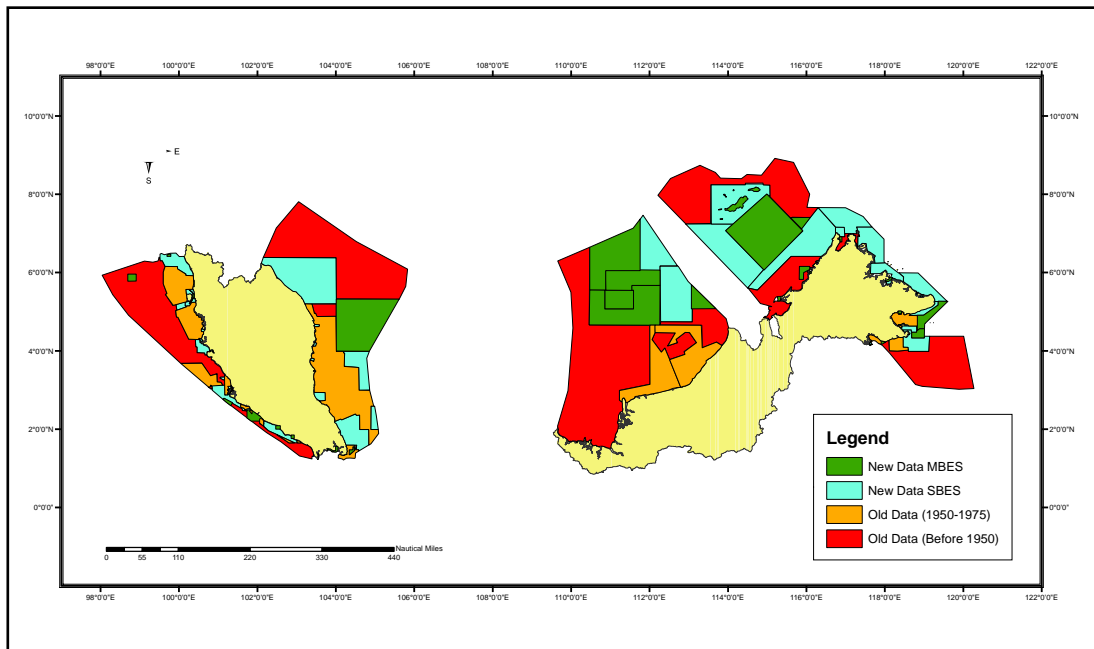
### 1.1 Background of Study

According to the National Aeronautics and Space Administration (NASA), there are more complete maps of the surface of the Moon or Mars than the ocean floor of Earth (NASA, 2016). Geographical facts indicate that water covers close to 70 per cent of the earth's surface, yet only less than 15 per cent of the seafloor area worldwide have been appropriately surveyed using shipborne measurements (Copley, 2014). Apparently, the majority of such survey activities have been made along the major shipping routes of the world. This is because the production of navigational charts were originally regulated based on Chapter V of the International Convention for the Safety of Life at Sea (SOLAS), where there is an obligation under the Convention to provide safe routes for shipping (IMO, 1974). Therefore, it is of no surprise to find that the majority of the surveyed area globally only focused on the shipping routes of the world. This typical worldwide setting has left an expanse of unsurveyed territory, mainly in the very remote areas and shallow water spaces within nearshore which are unsafe for navigation. This situation also occurs in Malaysian waters, where the majority of hydrographic surveys conducted in Malaysia are only focused on the main shipping routes.

According to the database provided by the Malaysian National Hydrographic Centre (NHC), the majority of shallow water areas, both in Peninsular Malaysia and Sabah and Sarawak near the shorelines are still unsurveyed. The database map in Figure 1.1 shows the status of hydrographic survey data comprising of 4 categories as follows;

- a. New data from Multibeam Echosounder System (MBES);
- b. The new data from Singlebeam Echo Sounder System (SBES);
- c. Old modern data (1950 – 1975), and;
- d. Very old data (before 1950).

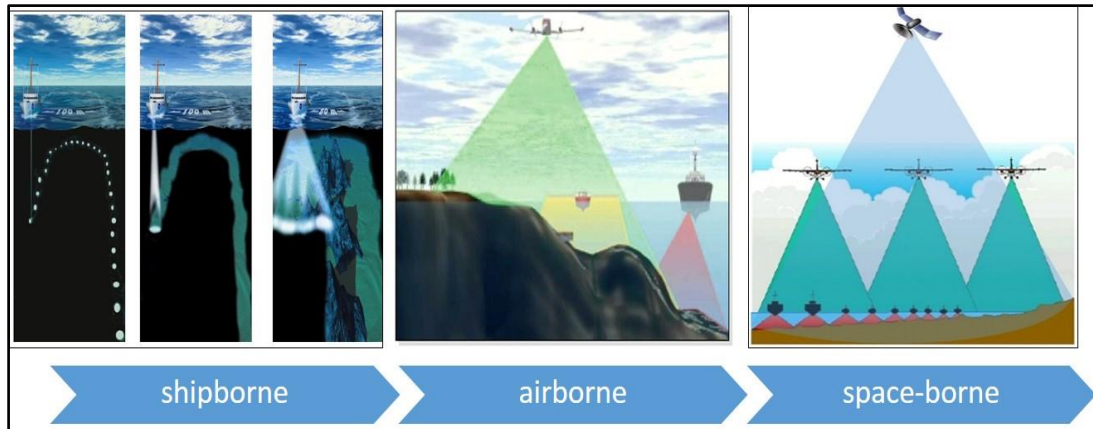
This database was updated until November 2017. The map shows significant gaps in the shallow water areas especially on the East Coast of Peninsular Malaysia and nearshore of Sarawak. There is no getting away from the fact that nearshore hydrographic data are imperative these days. Concurrently, the demand for bathymetry data has increased exponentially in recent years for maritime-related industries, especially for nearshore marine base activities. The demand has tremendously increased as more fields require the information primarily for the use of marine navigation, environment protection management, marine resources exploration and exploitation, fishing industry, marine science research, maritime defense, tourism and recreation, national spatial data infrastructure and maritime boundary delimitation (IHO, 2005).



**Figure 1.1** The hydrographic survey data status in Malaysia (NHC)



The growing demands from various fields have shaped the evolution of the acquisition technique of bathymetric data; from a shipborne platform to airborne and even using space-borne acquisition (Pe'eri *et al.*, 2014). The discovery of the electromagnetic spectrum (EMR) being able to penetrate water space leads to the breakthrough acquisition technique of extracting bathymetric data from space-borne platforms. Figure 1.2 describes the evolution of the bathymetry data acquisition technique from shipborne to the space-borne platform. The space-borne bathymetry acquisition technique for shallow water areas which is also known as Satellite-Derived Bathymetry (SDB) is more than just mere rhetoric. The rapid and vast development of remote sensing technology has brought in SDB as a new revolution to the hydrographic surveying (Stumpf *et al.*, 2003; Louchard *et al.*, 2003; Brando and Dekker 2003; Lyzenga *et al.*, 2006; Albert and Gege, 2006; Vanderstraete *et al.*, 2006; Su *et al.*, 2008; Bachmann *et al.*, 2012; Flener *et al.*, 2012; Doxani *et al.*, 2012; Bramante *et al.*, 2013; Pe'eri *et al.*, 2014; Tang and Pradhan, 2015; Ehses and Rooney, 2015; and Chybicki, 2018).



**Figure 1.2** The evolution of bathymetry data acquisition technique

In recent years, remote sensing technology via the airborne acquisition has been accepted as an alternative technique in the bathymetric data acquisition process among the hydrography communities, especially in the shallow water area. Thus far, for seafloor mapping within shallow coastal waters, the Light Detection And Ranging (LiDAR) which is an airborne bathymetric acquisition technique, has been deployed in various countries including Malaysia. Indeed, LiDAR has produced reliable

bathymetric data which is capable of achieving 20 cm vertical accuracy (Pe'eri *et al.*, 2014). In certain conditions, undoubtedly this technology is capable of meeting the International Hydrographic Organisation (IHO) Special Order survey requirements. Table 1.1 describes the nominal maximum detectable depth by various airborne bathymetric acquisitions (Lillycrop and Banic, 1993; Finkl *et al.*, 2005; Brock *et al.*, 2004). The data demonstrate clearly that these airborne acquisition techniques are commonly able to penetrate quite significant depths and achieve acceptable vertical accuracy. Nonetheless, there are still limitations in this airborne acquisition technique.

**Table 1.1:** LiDAR systems nominal maximum detectable depth

System	Developed By	Nominal Maximum Detectable Depth
SHOALS (Scanning Hydrographic Operational Airborne LiDAR Survey)	Teledyne Optech Incorporated, Canada	40 m
LADS (Laser Airborne Depth Sounder)	Tenix LADS Corporation, Australia	70 m
NASA EAARL (Experimental Advanced Airborne Research LiDAR)	NASA, United States	25 m

The major limitation of airborne bathymetric acquisition is not just on the maximum penetration range which depends heavily on water clarity, but the practicality in implementing this method on survey ground. The issuance of permits to operate a LiDAR system is the primary concern for the service providers while operating in a semi-enclosed maritime region like Malaysia. It is challenging to manage the flight path without entering the territory of neighbouring states, and the situation can trigger untoward incidents between both parties. With all the perilous

issues, the operation cost of a LiDAR system in this region can be extremely high, especially when the application is for chart updating which requires more frequent flyovers (Minghelli-Roman *et al.*, 2009; Pe'eri *et al.*, 2014). Hence, with more new satellites being launched and new sensors developed every year, a noteworthy number of research whether international or local, have been conducted to assess and analyse the SDB acquisition techniques since this remote-sensing technology is considered as an attractive option for seafloor mapping (Bramante *et al.*, 2013; Pe'eri *et al.*, 2014; Chybicki, 2018 ).

## 1.2 Problem Statements

An operating surveying platform for bathymetry data acquisition in the shallow water area, which is defined as an area having a depth less than 15 meters, is always considered to be a high operational risk due to limited navigation availability. The shipborne soundings commonly in use is a Singlebeam Echo Sounder System (SBES) that often produces a low spatial resolution (Lyzenga, *et al.*, 2006; Kanno, *et al.*, 2011). Hence, considering the limitation of the shipborne acquisition remotely sensed data technique, either the active technique (airborne) or the passive technique (space-borne) would be the best available option to be utilised instead. In addition, bathymetry data derived from the remote sensing platform is not something new for hydrographic application (Gould *et al.*, 2001; Stumpf *et al.*, 2003; Louchard *et al.*, 2003; Brando and Dekker, 2003; Lyzenga *et al.*, 2006; Albert and Gege, 2006; Su *et al.*, 2008; Bachmann *et al.*, 2012; Flener *et al.*, 2012; Doxani *et al.*, 2012; Bramante *et al.*, 2013; Tang and Pradhan, 2015; Su *et al.*, 2015; Vinayaraj *et al.*, 2015; Guzinski *et al.*, 2016; Toming *et al.*, 2016; Jegat *et al.*, 2016; Chybicki *et al.*, 2018).

Although SBD has received substantial attention by researchers in the recent decades, unfortunately, most of the studies have primarily focused on the development and enhancement of the established algorithms which are more inclined to remote

sensing environments (Doxani *et al.*, 2012; Bramante *et al.*, 2013; Su *et al.*, 2015; Vinayaraj *et al.*, 2015; Guzinski *et al.*, 2016; Toming *et al.*, 2016; Jegat *et al.*, 2016; Mohamed *et al.*, 2015; Martins *et al.*, 2017; Allen *et al.*, 2017). Indeed, most of the outcomes from the above studies are indirectly beneficial to the hydrographic survey industry. However, most of the studies did not address a significant issue which mystifies the surveyor community in Malaysia; which is acknowledgement of the detail accuracy of the depth estimations produced by the SDB technique. Precision and accuracy are always the subject of interest to surveyors. However, this part went unreported in most of the studies.

To embrace the SDB technology in the hydrographic surveying industry, the depth estimations produced by the SDB need to be analysed with the requirements laid down in the IHO Standards for Hydrographic Surveys (IHO, 2008). Therefore, it is timely to have a detailed study in this country to assess, evaluate and analyse the capability and consistency of SDB outcomes in Malaysia's environment settings comprehensively together with the standards specified by the hydrographic surveying industry. Furthermore, the 'local settings' which refers to the tropical environment consist of entirely different parameter settings as compared to most of the above-mentioned studies that were cited.

### **1.3 Research Questions**

Since the SDB technology is relatively new to the hydrographic industry in Malaysia, one question that was posed amongst surveyors about this technology is on the acceptability of the data provided from satellite remotely sensed technique concerning surveying industry practicality. Bramante *et al.* (2013), Pe'eri *et al.* (2014) and Tang and Pradhan (2015), used available soundings (depths) from the Electronic Navigation Chart (ENC) and bathymetric charts for the algorithm in deriving depths data. The results generated from the analysis might be sufficient enough and relevant

to other field applications such as reconnaissance of chart adequacy, managing of the coastal zone and marine biodiversity modelling and so forth. However, in the surveying industry, the level of accuracy demanded is comparatively higher. In addition, the issue of consistency also needs to be addressed.

Therefore this research is addressing the gap identified from the reviews as above. The analysis of the gap has shaped a few fundamental research questions;

- a. Which is the most practical algorithm model to adopt in this country's tropical weather and muddy water condition?
- b. How reliable is the SDB technology in producing a consistent level of accuracy in the field of hydrographic surveying, especially for the shallow water area?
- c. Which class of survey standard (IHO) that this technology is capable of achieving?
- d. What improvement can be developed to simplify the current processing procedure that can be adapted into hydrographic surveying application?

#### **1.4 Research Objectives**

This research focuses more on utilising the technology of the optical remote sensing tools to derive bathymetry data for hydrographic surveying applications. In general, this research has successfully explored in detail the ability of light penetrating the body of water through various available techniques and algorithms in which it has provided a physical basis for modelling of bathymetry data from a few types of multi-spectral satellite data. As the field of SDB is still new in Malaysia, the primary

objective that is set for this research is to identify, examine and develop the most practical SDB method which is capable of delivering the best outcomes for shallow water hydrographic mapping. In order to meet the desired aim, the research is focused on the following objectives.

- a. Objective 1: To identify the performance of the empirical model algorithms, Lyzenga and Stumpf, in deriving bathymetry data modelling from multi-spectral satellite imageries in a tropical environment;
- b. Objective 2: To determine the level of reliability produced from the algorithms focusing on the shallow water area which reflects on the hydrographic mapping applications.
- c. Objective 3: To assess the degree of accuracy and standards of bathymetric data derived from SDB technology in meeting the standard and specifications laid by IHO.
- d. Objective 4: To develop the new calibration of the SDB empirical method with an optimisation technique focusing on the tropical environmental parameter.

## **1.5 Scope of Study**

The introduction of a high-resolution multi-spectral imagery satellite was a catalyst in the the SDB field for it to be a fast-growing technology and ultimately has fascinated a significant number of researchers around the globe. Consequently, the study scope has been reshaped and re-aligned in order to achieve the desired objectives. Thus, the study has placed emphasis at the critical stage of the processing part which deals in confronting the bottom reflectance in determining the bathymetric

model in the shallow water area where the interest of the area will incline into identifying the TSB. Indirectly, this approach will minimise the discussions on the other processing parts, such as the sun glint removal and atmospheric correction stages. In deriving the bathymetric data from satellite imageries, this research focused on the capabilities of few satellite imageries. To have variety in evaluating the outcome of SDB, this research adopted three type of satellite imageries. Table 1.2 lists down in detail the kind of satellite imageries and the bands which will be used for the research.

**Table 1.2:** List of satellite imageries and bands used

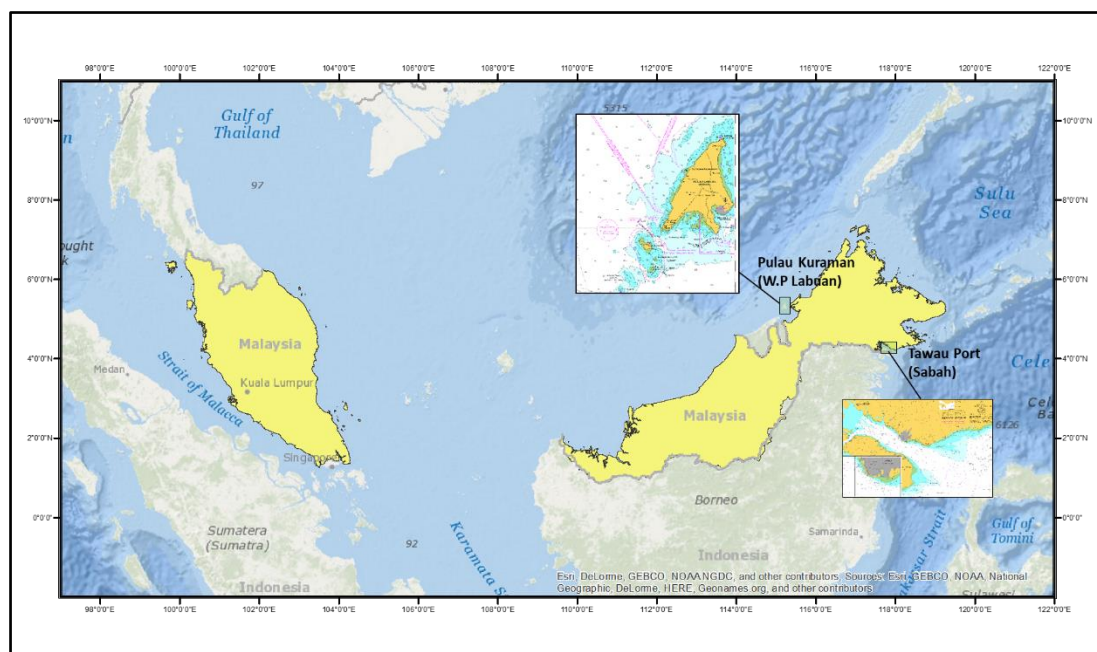
<b>Satellite Data/ Category</b>	<b>Spatial Resolution</b>	<b>Wave Length Bands (nm)</b>	<b>Area/Date Captured</b>
Sentinel 2 (High- Resolution)	10 m	Blue: 447 to 545 Green: 538 to 582 Red: 645 to 682 Near IR: 763to 907	Tawau (29 Nov 2016) Labuan (28 June 2017)
Pleiades (Very High- Resolution)	2 m	Blue: 430 to 550 Green: 500 to 600 Red: 590 to 710 Near IR: 740 to 940	Tawau (12 July 2016)
WorldView2 (Very High- Resolution)	0.5 m	Coastal Blue: 400 to 450 Blue: 450 to 510 Green: 510 to 580 Yellow: 585 to 625 Red: 625 to 695 RedEdge: 705 to 745 Near IR: 770 to 895 Near IR2: 840 to 1040	Labuan (26 June 2015)

## 1.6 Study Areas

Two (2) areas with contradicting seabed parameters conditions were identified for this research. The selection of Tawau Port (Sabah) and Pulau Kuraman (Wilayah Persekutuan Labuan) as study areas are aligned in meeting the research objectives

where at least two (2) areas with different coastal seabed topography parameters were fully tested. Availability of data (bathymetry, tidal and satellite images) was the primary criteria for choosing both locations as study areas. At the same time, both areas perfectly met the parameters required for this research.

The main feature for the Tawau Port study area is a protected coastal area with a low gradient condition (coastal type 1P and 1M) which holds a typical condition of relatively high water turbidity. This condition is considered as the standard criteria for the majority of the coastal regions in Malaysia. Thus, the results from Tawau Port is capable of representing the majority of shallow water conditions in Malaysia. Whereas, Pulau Kuraman study area consists of a very different water condition and different seabed topography parameter. Although the water clarity is better as compared to Tawau Port, Pulau Kuraman is an exposed coastal area (coastal type 2E and 3E) which has an irregular seabed topography. The condition is due to the diversity of the seabed classifications which are a mixture of sand, coral, rock, seaweed and seagrass. Figure 1.3 indicates the geographical location of both study areas.



**Figure 1.3** Geographical location of the study areas, the Tawau Port (Sabah) and Pulau Kuraman (W.P Labuan)



## **1.7 Significance of Study**

This study has delivered a significant contribution to various fields, especially primary stakeholders such as NHC as the national focal point for all hydrographic surveying activities. Likewise, to the Department of Survey and Mapping Malaysia (DSMM), this research has provided a new approach in assisting the authority to update the national Territorial Sea Baselines (TSB). Nevertheless, this research did not fall short in delivering significant research novelty.

### **1.7.1 Delivering New Guidelines to Malaysian Hydrographic Industry**

The most significant outcome of this research is the answer to whether the SDB technology is acceptable in the field of hydrographic surveying in this country. The SDB technology is considered as a new method for bathymetry data acquisition. There are a number of algorithms and techniques available in deriving bathymetry data. However, not all algorithms and technologies are suitable in term of practicality for the hydrographic surveying industry in Malaysia. Therefore, this research has successfully addressed the uncertainties and ambiguities by finding the suitable algorithm and technique to be adopted in Malaysia. This positive outcome will undoubtedly be able to assist in the challenging task of the NHC in filling in massive gaps of data on the very shallow water areas nationwide.

In conjunction with Universiti Teknologi Malaysia, a research university alongside the National Blue Ocean Strategy concept, this research has also facilitated the NHC as the national authority in developing a new set of guidelines in SDB acquisition technique and to provide the direction for the surveying industry in the country on this rapidly developing SDB technology. On top of that, this research has also assisted the NHC in participating with the IHO Technical Working Group under

the Hydrographic Services and Standards Committee (IHO, 2015b), to study and develop the standards for the SDB technology as a new surveying method. As the standard for SDB technology is now in the pipeline, this research delivered a significant contribution to NHC as the outcomes have portrayed an accurate view of the capability of this promising technology to be adopted in this country.

### **1.7.2 Identifying The Nation's Territorial Sea Baseline (TSB)**

The other stakeholder who directly benefited from this research is DSMM as the lead agency in maritime delimitation activities. Malaysia has a total of 55,6285 km<sup>2</sup> maritime area as compared to 329,960 km<sup>2</sup> of land area (NHC, 2016). This sizeable maritime area rationalises Malaysia to have more maritime neighbours as compared to the land neighbours (Haller-Trost, 1998; and Forbes and Basiron, 2008). Therefore, there is a necessity to address the question; where does the sea begin? Technically, under the Convention, the datum or the starting line for measuring the width of maritime jurisdictional zones encompassing from the coast seaward is the Territorial Sea Baseline (Forbes and Basiron, 2008).

According to Article 5 of the Convention, *“the normal baseline of a coastal state is the low-water mark as delineated on the large-scale charts adopted by the coastal state”* (United Nation, 1982). From this datum, the zone of jurisdiction, as provided in the UNCLOS 1982, namely the Territorial Sea (Article 3), the Contiguous Zone (Article 33), an Economic Exclusive Zone (Article 57) and the Continental Shelf (Article 76) are measured. Undeniably, all these articles demonstrate the importance for a coastal state to determine the TSB, which must then portrayed on charts (Reed, 2000; Prescott and Schofield, 2004 and Schofield, 2012). The only method of defining the national TSB is through bathymetry data collection. Therefore, the coastal state shall utilise the unsurpassed acquisition method available to produce the optimum outcomes.

Although DSMM had carried out a complete detail survey to identify national TSB, nevertheless, the surveying method which was adopted more than 14 years ago is arguably was not the best method to be applied as the Single Beam Echo Sounder System (SBES) was manifestly unable to provide comprehensive coverage. As better technology is now available, it is timely to revisit the whole process and implement the latest technology for the benefit of the country. Indeed, the positive outcomes from this research can undoubtedly be utilised by DSMM as a tool to assess our current TSB. Theoretically, by adopting this SDB technology, the data coverage becomes more substantial and a comprehensive coverage can be visualised. This approach is ideally capable of discovering some potential new low water line and low tide elevation within the whole nation shallow water areas. If this happens, this research certainly will be beneficial to Malaysia as we might gain more territory in our maritime zones.

### **1.7.3 Providing Significant Research Novelty**

In the perspective of research novelty, this research has produced a new technique for SDB calibration. M-LOT is an in-house tool developed using MATLAB software which applies the combination of the least square adjustment method and linear correlation algorithm which has successfully improved the results in terms of quality and consistency. In general, the hardest part of the processing of the SDB application is the depth calibration process before applying the empirical inversion model. The conversational process is not only time-consuming but also requires additional skills and experiences of the hydrographic surveyor. M-LOT has simplified the painstaking element and has been proven in making the process easier in deriving bathymetry data from SDB application.

## **1.8 Thesis Outline**

This research thesis consists of six (6) chapters which are Introduction, Literature Review, Research Methodology, Model's Calibration and Depth Derivation Results and the Results and Analysis. The detailed thesis outline of all chapters are elaborated in the following sub-paragraphs.

### **1.8.1 Introduction**

The first chapter of this thesis is an introduction chapter. This chapter presents the general view of this research which covers Background of Study, Problem Statements, Research Questions, Research Objectives, Scope of Study, Study Areas, Methodology and Significance of the Study.

### **1.8.2 Literature Review**

This chapter discusses the literature studies on related research works especially on SDB and divulges the research gaps. In addition, the technical information about multi-spectral images and remote sensing technology is also elaborated on. The topics discussed in this chapter are the Fundamentals of SDB, SDB for Hydrographic Mapping, types of Multi-spectral Satellite Imagery and Derivation Models used in SDB and the Research Gaps Finding.

### **1.8.3 Research Methodology**

This chapter illuminates on the methodology adopted for the research. All work processes in meeting every single objective were discussed comprehensively. The topics illustrating the workflow of this research which consist of the five (5) phases involved are the Pre-Research Phase, Data Collection Phase, Data Processing Phase, Depth Derivation Phase and Data Analysis Phase.

### **1.8.4 Model's Calibration and Depth Derivation Using Multi-Spectral Satellite Imageries**

This chapter discusses in detail the outcomes of the calibration and depth derivation processes. The calibration process that delivers the variables required for all three adopted model Lyzenga, Stumpf and M-LOT were described comprehensively. Consequently, this chapter also enlightens on the results that are obtained from models depth derivation. The subject discussed in this chapter are divided into Model's Depth Calibration Results and Depth Derivation Outcomes.

### **1.8.5 Result and Discussions**

This chapter illuminates in detail the final findings of the research. The discussion covers the quantitative evaluation of all depth derivation model outcomes and the analysis of the IHO survey standards assessment process. Furthermore, this chapter also comprehensively elaborates on the findings and performance of every single model including the level of improvement achieved by M-LOT. The

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