COMPARISON OF THREE MULTIBEAM ACOUSTIC WAVE PATH REFRACTION COMPENSATION TECHNIQUES

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DECLARATION

I declare that this thesis entitled "Comparison of Three Multibeam Acoustic Wave Path Refraction Compensation Techniques" is the result of my own research except as cited in the references. The thesis has not been accept for any degree and is not concurrently submitted in candidature of any other degree.

Signature :________________

Name : Loh Khai Xian

Date : 17th July 2014

DEDICATION

To my beloved family and friends.

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ABSTRACT

The main mechanism of bathymetry survey is relied on the measurement of the travel time of the two ways sound wave. Speed of sound wave is dependent on the water density. Density of every water layer is affected by temperature, salinity and pressure. According to Snell's Law, when sound wave travel through water layers with different densities, the travel speed will change and leads to refraction. Thus, the variation of sound speed will significantly affect the accuracy of the bathymetry result, as the refraction will cause the sound wave to be refracted from their ideal propagation path, and, resulting false depth and position. Compensation of the refraction can be completed by Trigonometry Method, Curvature Method and the Combined Method. The Trigonometry Method is implementing the averaging of the sound speed for a determined layer of depth. Conversely, the Curvature Method assumes the sound wave to travel in an arc of circle of different radius in every different depth layer. Meanwhile, the Combined Method is the combination of the Trigonometry Method and Curvature Method. This study aims to identify which approach provides the better positional result and depth. The sound speed data of the water column is recorded using the sound velocity probe at four different study areas. The outer beam of the particular ping is selected for comparison and analysis. As a result, the average of overall difference in horizontal distance between Trigonometry Method and Combined Method obtained from 30° beam and 60° beam is 0.038m and 0.122m, respectively. From the simulation, as the sound speed increases or decreases continuously, the horizontal difference among Trigonometry Method and Combined Method exceeds the special order of International Hydrographic Organisation Standard (IHO) at the depth level where the sound speed exceed the difference of 10m/s from the transducer.

ABSTRAK

Mekanisma utama ukur batimetri adalah bergantung kepada cerapan masa perambatan dua hala gelombang bunyi. Halaju gelombang bunyi adalah bergantung kepada ketumpatan air. Ketumpatan air setiap lapisan dipengaruhi oleh suhu, kemasinan dan tekanan. Menurut Hukum Snell, apabila gelombang merambat melalui lapisan air yang berbeza ketumpatan, halaju gelombang akan berubah dan menghasilkan pembiasan. Justeru, perubahan halaju gelombang bunyi akan memberi kesan terhadap hasil kejituan batimetri, kerana pembiasan akan menyebabkan gelombang bunyi terbias dari laluan perambatan yang sepatutnya, dan menghasilkan selisih dalam penentuan kedalaman dan kedudukan. Pembetulan untuk pembiasan boleh dijalankan dengan Kaedah Trigonometri, Kaedah Kelengkungan dan Kaedah Gabungan. Kaedah Trigonometri menggunakan purata halaju untuk lapisan kedalaman yang ditentukan; Kaedah Kelengkungan menganggap gelombang bunyi merambat dalam bentuk arka bulatan di setiap lapisan kedalaman dengan jejari yang berbeza; Kaedah Gabungan merupakan gabungan Kaedah Trigonometri dan Kaedah Kelengkunan. Kajian ini bertujuan untuk mengenalpasti kaedah yang lebih baik dalam memberi keputusan kedudukan dan kedalaman. Data halaju gelombang bunyi direkod dengan pengesan halaju bunyi di empat kawasan kajian yang berlainan. Ping daripada alur luar dipilih untuk perbandingan dan analisis. Menurut keputusan yang diperolehi, purata keseluruhan untuk perbezaan jarak mendatar antara Kaedah Trigonometri dan Kaedah Gabungan yang diperolehi dari alur 30° dan alur 60° adalah masing-masing 0.038m dan 0.122m. Berdasarkan kepada simulasi, apabila halaju gelombang bunyi meningkat atau menurun secara berterusan, perbezaan jarak mendatar antara Kaedah Trigonometri and Kaedah Gabungan mencecah standard mimima Piawaian Organisasi Hidrografi Antarabangsa (IHO) pada paras kedalaman dari tranduser yang mencapai perbezaan halaju gelombang bunyi sebanyak 10m/s.

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LIST OF ABBREVIATION

ASCII	-	American Standard Code for Information Interchange
AUV	-	Autonomous Unmanned Vehicle
CTD	-	Conductivity Temperature Density
DGPS	-	Differential Global Positioning System
DoN	-	Department of Navy
DOSITS	-	Discovery of Sound In The Sea
FFT	-	Fast Fourier Transformation
GPS	-	Global Positioning System
IHO	-	International Hydrographic Organisation
MAHRS	-	Meridian Attitude and Heading Reference System
MBES	-	Multibeam Echosounder System
MRU	-	Motion Reference Unit
NDT	-	Non-destructive testing
NOAA	-	National Oceanic and Atmospheric Administration
NPL	-	National Physics Laboratory
QINSy	-	Quality Integrated Navigation System
ROV	-	Remotely Operated Vehicle
RTK	-	Real Time Kinematic
SBES	-	Single Beam Echosounder
SSS	-	Surface Sound Speed
SVP	-	Sound Velocity Profile
UNESCO	-	United Nations Educational, Scientific and Cultural Organization
USACE	-	United States Army Crops of Engineers
3D	-	Three dimensional

CHAPTER 1

INTRODUCTION

1.1 Background

The evolution of multi-beam echo sounders (MBES) is leading to systems with enhanced capabilities in their traditional markets, but also provides features to allow the expansion of their use into new areas and applications. This short review highlights some of the features of the latest generation of systems. The attributes of an MBES system are traditionally described by technical specifications, such as operating frequency, pulse length, beam width, number of beams and coverage. It is also apparent that potentially cost-effective systems are now available to users who may previously have only considered a single beam echo sounder (SBES) solution (Mann, 2013). The MBES transducer is continuously transmitting acoustic sound toward seafloor. When the acoustic sound makes contact with the bottom, it will be reflected back to the transducer as to complete a round trip. The beam array of MBES is pre-determined at the certain angle deviated at both side from the nadir. Each beam is constantly separated by a fix angle (Gunathilaka, 2008).

As mentioned by Koomans (2010), MBES have speedily established their superior competencies over earlier systems used to attain complete seafloor coverage. The distinctive capabilities of the MBES allow it to provide high accuracy full coverage of the bottom, that exceeding International Hydrographic Organisation (IHO) specifications. The fact that the MBES transducer is firmly mounted to the hull allows the user to compute its position as precisely as the current positioning system. Thus, MBES have become a widely accepted reliable system for various hydrographic tasks.

The implementation of Real Time Kinematic (RTK) Global Positioning System (GPS) has further improved the positional accuracy of MBES. By measuring the phase of the carrier wave of the RTK, centimeter level horizontal positional accuracy can be achieved (Yasuda, 1999). The accuracy of tidal measurement from electronic tide gauges has been proven reliable for many years. The accuracy of these real-time digital water level data is able to obtain centimeter level (Rabah, 2011). The sum of these errors is within the tolerance set by IHO. Therefore, the sound speed deviation and roll biases will be the critical factor in affecting the precision of absolute depth (Capell, 1999).

Sounding data from the MBES system is a product of processing information from numerous data sources. These comprise the heading of ship and attitude data from the gyrocompass and the motion sensor; vertical reference data (tidal data) from the tide gauge; horizontal positional data from the GPS unit and sound velocity data from the Conductivity Temperature Density (CTD) or Sound Velocity Profile (SVP) probe in addition to the basic MBES data itself. Data from each source are issue to singular errors which are contributing to overall data quality. To minimise these errors, system planners often have established error budgets for different components of the system (Gunathilaka, 2008).

1.2 Problem statements

Sound refraction artifacts are often present in multibeam swath bathymetry data. For a flat array, the artifacts are usually severe in outer beams than in inner beams. In a three dimensional (3D) topographical mapping they appear as along track ridges. To minimise the survey time, the outer beams should be utilized. Therefore, the refraction errors should be removed. The sound speed of the two upper layers has a constant gradient, and the third layer has the same sound speed as the most bottom measured layer. The model parameters can be searched based on the principle of the minimum difference of depth between the overlap of two adjacent swaths. The horizontal position and depth of each beam can be accordingly recalculated using the model parameters (Yang et al, 2007).

Ports, harbours and marine bases are regularly located in estuaries, where river discharge and tidal stirring stoutly influence the sound velocity profile. Scales of temporal and spatial variability are frequently inadequate, resulting in unexpected variation to the acoustic environment. Such diminutive estuarine SVP and temporal changes have considerable influences on sound propagation and therefore must be described and enumerated in order to optimise sensor performance (Priestley and Thain, 2010).

Monitoring underwater environments is important for future near-shore exploration and port safety. The efficiency of underwater acoustic sensor systems is affected by the water environment, as sharp gradients in salinity and temperature cause sound to refract and reflect. Sound transmission can be impaired in estuaries where the salinity of the water is highly erratic in space, and tidal action causes water conditions to vary as a function of time. Thus, the correction of refraction is important for near shore location (Shi and Kruger, 2009).

Tides and an altering existence of salt and freshwater from river flow can cause significant variation of the water column SVP at the dynamic water environments, such as the estuaries, harbours and ports. It is important to sufficiently compensate bathymetric data for sound refraction effects in the face of limited SVP information. In practice, refraction correction can be hindered by insufficient knowledge of the water-column SVP at the time and place of MBES measurement (Jeroen, 2007).

The research on the effect of refraction and compensation of propagation path is inadequate in Malaysia. According to Kammerer (2000); Yang et. al (2007); Plaa, Snellen and Simons (2008), the depth uncertainty due to refraction can be eliminated via interpolation of adjacent swath. Moreover, Imahori and Hiebert (2008) cited that the total depth uncertainty can be estimated using Combined Uncertainty and Bathmetry Estimator (CUBE) algorithm. However, the monitoring of the propagation path was not mentioned. Cartwright (2003) and Medwin (2005) stated about the ray tracing techniques that can be used to monitor the effect of refraction towards propagation path, but the comparative study regarding the techniques is not performed.

This study discussed about the comparison of compensation approach of Layer with Constant Sound Speed (Trigonometry method) and Layer with Constant Sound Speed Gradient (Curvature method). Both approaches are mentioned by Kammerer (2000), Cartwright (2003), Medwin (2005) and Andersson (2008) in previous. However, the comparison of both approaches was not carried out. In addition, the setback of the inability of Curvature method to handle continuous unchanged sound speed layer is not mentioned. In this study, Combined Method is designed to solve the inability of the Curvature method to compute the data consist of zero gradient sound speed layers.

According to the Gunathilaka (2008), the approach of constant SVP is common to remove uncertainty in refraction. In fact, the sound speed does not change abruptly from layer to layer, but it changes gradually from the water surface to seabed. Henc, the approach of assuming the sound speed change constantly per layer is unfeasible to handle all kind of refraction situation, as the beam does not propagates in the line of sight in that particular layer (Figure 1.2). However, the beam is expected to be propagated in the curvature line that bends gradually when heading towards the seabed. Thus, new approach should be considered to monitor the actual path of the beam.

1.3 Research objectives

The objectives of this research are:

1) To develop algorithm to calculate the fittest curvature gradient for refracted sound velocity profile.

2) To compare the point position of the refracted beam on the seabed obtained from Trigonometry method, Curvature method and Combined method.

1.4 Scope of study

The SVP does not experience great change in open sea, as the physical characteristic of water column is approximately similar. However, the dynamic fluctuation of seawater and freshwater at estuary area or at port will cause the SVP to vary erratically and inconsistently. Therefore, for this study, the research is carried out at Lido Beach, Lumut, Penang and Kota Bahru. In addition, simulation data are used for the study as well. Information on the data are discussed thoroughly in Chapter 3.

The MBES is used in this research is RESON SeaBat 8124 which is Mill's cross type with flat array. The system consists of 80 beams with swath coverage that can exceed 120 degrees. Each beam is separated 1.5 degree from each other. In addition, the accuracy of the system is compliant International Hydrography Organisation (IHO) standard.

SVP probe is used to measure the sound velocity profile throughout the water column. Meanwhile, the SSS is measured using the surface sound speed-measuring probe located at the face of the transducer. The rate of sound velocity recording is set to 0.25 meter or 0.5 meter depth interval depends on the requirement of the study.

Tidal reading is collected using automatic tide gauge, Valeport. Motion sensor and positioning system are installed onboard. The embodiment of all instruments is measured. MBES bathymetry data gathering and processing is completed using QINSy Version 7.5.

The SVPs under both circumstances are obtained and compared correspondingly. The profile obtained from both methods is generated for evaluation. Additionally, the difference in depth is compared as well.

In order to process and analyse the refraction information, a computational program is developed using the Microsoft Excel. Filtered data is inserted in the program, and the required parameters will be calculated using the developed program.

1.5 Significant of research

Since the development of MBES, refraction of acoustic ray in water column frequently leads to errors in depth. The estimation of ray path in the industry is usually using the step gradient approach, which less compromises to the refracted path. Thus, the accuracy of the most feasible distance travelled may be degraded, hence, influence the depth and position measurement.

The research will provide an overview on the influence of variation of sound speed and profile toward bathymetric measurements. The variation will cause the disputation over depth and horizontal position. In addition, the risk of grounding can be reduced, if the depth and position is measured properly.

In Malaysia, the research on the effect of refraction in beam propagation is inadequate. The knowledge is very important for hydrographers to take into account when survey is being conducted. Thus, proper study has to be carried out, as the MBES has became the mainstream hydrography survey instrument in the sector. This study will provide the information regarding the comparative study of the different techniques for compensation of refraction at propagation path.

The comparison on Trigonometry, Curvature and Combined methods is yet to be carried out in any previous study. As we all know, the variation of ocean characteristic is unpredictable. It is impractical to handle all scenarios with single approach. Hence, this study can offer the novel information for the approach to be taken on refraction study.

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