On Methods of Multi-beam Data Error Correction

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***Abstract*- According to analysis to the error sources of the multibeam sonar system，corresponding methods are applied in different error correction processes. The method of filtering is adopted to reduce sounding noises. To the calibration error， recalculation is amended to correction. As to the sound speed profile error, marginal beams are deleted and Equivalent Sound Velocity Profile method is brought to diminish the effect of the error. In this paper the method using the single beam data as a reference to correct the integrated errors of the multibeam data are detailed. All the methods that have been applied in the 908 projects of State Oceanic Administration achieved good results.**

I. INTRODUCTION

Multi-beam sounding system is the most popular equipment in marine topography survey. It has a good reputation for full coverage, high resolution and high efficiency. These advantages make multi-beam sounding system be widely used in Chinese marine survey. However, errors in multi-beam sonar are inevitably produced during installation, calibration and measurement process. Some of them can be corrected in the post-processing and some wouldn't. How to eliminate these errors is the bottleneck problem to achieve high-precision multi-beam results.

In the 90s of last century, foreign scholars begin to do research on the error source and correction of multi-beam system. A detailed study showed that the attitude of the transducer and acoustic refraction line are two important factors on the accuracy of multi-beam system. [1,2]. After a large number of data analysis D. F . Dinn from Canadian and Helene Tonchia from French confirmed that sound velocity error mainly affect beam pointing angle and beam path of multi-beam system. And they presented a specific quantitative analysis. The method to determine the velocity profile error based on multi-beam data was published by William J. Capell [3]. During the same period Professor J. E. Hughes Clarke from NEW BRUNSWICK University of Canada brought up other methods dealing the sound velocity correction, which included the alternative velocity profile, the sound velocity profile interpolation and the geometric rotation in data post-processing [4]. In 2000, Dr. Edouard Kammerer from NEW BRUNSWICK University of Canada, studied on refraction of multi-beam data and came up with several refraction correction methods 'OMG Refraction Tool', 'BatCor Method', and 'Method of the 45 º Beams' in his PhD thesis [5]. OMG launched corresponding refraction correction software.

In this paper, several available multi-beam data-processing algorithms in commercial software are applied in error correction process. To those errors could not be eliminated in the post-processing, a new method using single-beam data as a reference source for a comprehensive multi-beam data error correction is detailed. It has been applied in China 908 Project and the accuracy of the result proved to be improved.

II. ERRORS IN MULTI-BEAM AND PROCESSING

A. *Errors in Instrument Calibration and Processing*

Multi-beam instrument calibration includes shipping Heading, Roll, Pitch and Time delay calibration. Among them, the roll bias is the most important one which can cause a great impact on the measurement accuracy. The following topic focuses on roll error, and approaches to other calibration errors are similar.

Roll calibration is a compensation for a probable horizontal angle error caused by transducer installation in multi-beam system. Roll error would eventually cause a certain angle between actual seabed and the surveyed one. In the monitor, the beam all tilt with an angle and two adjacent lines shown V-shaped are difficult to merge [6]. This phenomenon is particularly evident in flat seabed terrain (shown in Fig. 1). In the data post-processing, flat terrain will be found with slope, and larger margin error would occur when the adjacent beam line merges.

The error elimination processing is similar to pre-calibration method.

First of all, the value of the roll bias D_R is calculated by (1). D_Z is the depth difference between two adjacent survey lines with opposite direction at the point *Da* which has a few distances along the line perpendicular to the track of the ship.

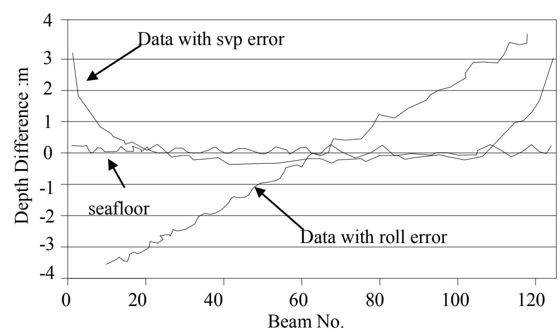

Figure 1. Sketch map of multi-beam data error

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$$D_R=[\tan^{-1}(D_Z/D_a)]/2 \quad (1)$$

Different position of the points can be measured in seeking a mean roll deviation value.

Secondly, according to D_R, the depth data will get a horizontal tilt correction to achieve overlap region coincide in two adjacent bathymetric data swath.

B. *Errors in Noises and Processing*

Noises have a lot of resources [7], they mainly include following parts.

Noises caused by bad sea conditions. Bad sea conditions make great impact on the accuracy of seabed topography and that's why strict requirement specification is made in seabed topography survey. Even under the qualified sea conditions, the continual swing of the vessel will still generate noises.

Noises caused by instruments. Multi-beam system is a complex system which would create the instrument noise if the installation or operation is inappropriate ended with a lot of false signals or deactivated beam.

Noises caused by other features, such as abnormal seabed topography; false signal generated because the water depth is too shallow or too deep to excess the apparatus range; multiple reflections generated by undersea structures; disturbance of the water by fish interference or other causes. No matter what kind of noise, always present high-frequency characteristics, deviate from the real data. Fig. 2 indicates that a multi-beam bathymetric distribution characteristics of noise.

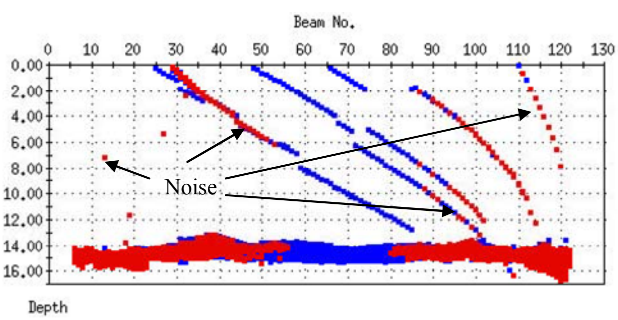

Figure 2. Multi-beam data with noise

Noises process mostly means to eliminate gross errors. The most popular method is using specific filtering to clean up anomalies automatically or manually. Almost all the multi-beam data processing software adopt statistical method to deal with errors by comparing the points of interest with adjacent beam line. If the value is not in the threshold it will simply be deleted. These software differ from their options in the neighboring beam, statistical calculations and acceptance criteria. They might use different parameters like maximum-minimum depth threshold, maximum gradient, minimum angle, horizontal distance, standard deviation to filter jump points. Currently, many types of software such as CARIS HIPS multi-beam data processing package, Fledermaus interactive 3D visualization software, Hypack multi-beam processing software, all have adopted CUBE (Combined Uncertainty and Bathymetry Estimator) method of filtering. The method based on the measured depth information of the survey area grid called node gives an estimate to its associated error [8-10]. Estimates of individual nodes would be selected to use the water depth points first in order to increase the anti-poor character and median filtering and dynamic Kalman filter would be applied to generate the values. The principle of CUBE is to obtain the best depth estimate among all the values.

C. *Errors in Sound Velocity Profile and Processing*

Multi-beam bathymetry survey relies on the spread of sound in seawater and seabed scattering. The water depth is measured mainly by the time and speed of the sound. Therefore, the sound velocity profile errors have a significant impact on not only the depth of the points, but also their horizontal position. It is the most important error source, especially for the edge beam with large open angle multi-beam system because they have smaller grazing angle. The accuracy of sound velocity is demanded to be very high because even a small error at first could lead to a serious consequence in the end [11].

Sound velocity is measured under very strict requirements according to the technical specification. But there are so many factors affect sound velocity: time, space, temperature, salinity and other marine environment and so on. So it is hard to guarantee the selected sound velocity is the most appropriate for multi-beam measurement accuracy. Fig. 1 shows sound velocity data with errors. The edge beams will bend upward or downward if errors existed in sound velocity data. The effect gradually increases from the central beam to the edge beam.

In the post-processing, two methods are used in error correction. (1) Delete the edge beam. The impact of errors on a flat seabed is often manifested in the edge beams bending upward or downward and gradually increases from the central beam to the edge beam. So delete the edge beam is a good method to remove all the large errors in water depth. This method only used when the error is relatively small and the adjacent beam lines overlap enough. (2) Re-fitting the best sound velocity profile: As the sound velocity profile leads to the survey error, good results will achieve simply by using a more appropriate sound velocity profile to replace the previous one. The key is how to get the best sound velocity profile since the speed of sound is changing over time and space. In processing, the method of equivalent velocity profile is adopted to correct sound beam refraction. When it comes to calculate the position of beam footprint, a simple sound velocity profile could always be found to be alternative to the actual one. The principle of the multi-beam sounding system indicates that the sound velocity profile has the least impact on the central beam because it is perpendicular. That's why it reflects the true value of the actual water depth. So an equivalent sound velocity profile can be made to correct the edge beam [12-14]. Using this method the seabed topography is required to be relatively flat. The sound velocity profile is the fittest for the correction when the residuals of the bathymetric data tend to be minimum.

III. MULTI-BEAM COMPREHENSIVE ERROR CORRECTIONS

After the above-mentioned error corrections, the multi-beam data accuracy could be enhanced to meet the specifications. However, unlike single-beam system, multi-beam measurement system is a set of sensors with more external apparatus to work together, and this determine the precision of the system is subject to the impact of these external auxiliary equipments.

Among these accuracy factors some will be superimposed with each other to multiply the final data errors. For example, roll error could make sound velocity profile error multiplied several times to decrease the accuracy of edge beam data significantly. At present, it is impossible to eliminate all the errors completely even after the post-processing. The chart mapped from the qualified data which meet the specification requirements shows the existence of clear error in the flat terrain areas not only affects the appearance but also leads to a wrong trend in contour line. It is quite necessary to find a way to carry out comprehensive error corrections.

The data in Fig. 3 shows how much difficulty roll error plus the poor sound velocity profile could cause in the sonar map mosaic. The result after the correction does not ideal. Water depth in the central beam failed to be in accordance with the edge beam and bring many difficulties in splicing.

Figure 3. Shaded relief image (before correction)

An approach using a single-beam data as a reference to correct the error in multi-beam is detailed here.

Over several decades of development, single-beam sonar system has reached a very high level in stability and precision. Its accuracy is approximately equal to multi-beam, so it can be used as alternate error compensation to the multi-beam.

The main data processing is detailed as follows:

(1) Three single-beam test lines are set up perpendicular to the survey lines of multi-beam. The difference of the data in the convergence point could be got by subtracting the value obtained from each system.

(2) The error distribution map could be established from these errors points using inverse distance weighting method to build a proper Error model, shown in Fig. 4. From the Fig. 4, the direction of the error contour basic tends the same direction of multi-beam sounding beam reflecting errors in the multi-beam edge beam.

(3) The topographic maps after the correction can be drawn by subtracting Multi-beam model and the error model. Shaded relief image after correction is shown in Fig. 5. It is apparently that the topographic maps are improved in vision, and the errors in the central beam and the edge beam both are greatly reduced.

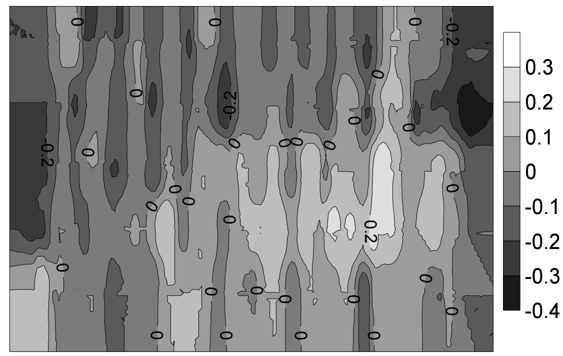

Figure 4. Error distribution chart

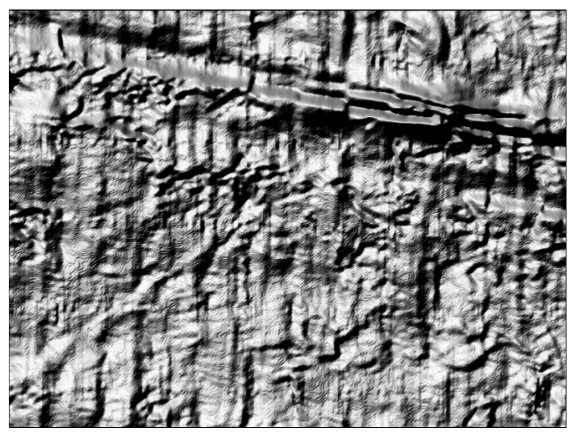

Figure 5. Shaded relief image (after correction)

IV. CONCLUSIONS

According to analysis to the error sources of the multi-beam sonar system，corresponding methods are applied in different error correction processes. All the methods that have been applied in projects supported by Chinese Oceanic Administration achieved good results. Noise, calibration error and sound velocity profile error are the main source of multi-beam system. In the post-processing there are several methods to eliminate these errors. For those errors can not be completely eliminated, using a single-beam data as a reference is applied to build an error model that could adjust the seabed terrain. The overall accuracy of the data will be improved and the maps will be better in vision.

This paper gets a strong practical merit on multi-beam data processing. It could be a guidance for the follow-up multi-beam survey, but also a reference to multi-beam post-processing software development.

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