Technical Aspects of Marine Scientific Research for Continental Shelf Outer Limits: Advanced Method of Multi-beam Data Processing to Obtain Detailed and Precise Bathymetry

Yasutaka Yokoi
Ocean High Technology Institute, Inc.
yokoi@ohti.co.jp

Tadahiko Katsura
Japan Hydrographic Association
tkatsura@jha.jp

Introduction

Comprehensive and detailed bathymetric data derived from the multi-beam echo sounding measurement are useful to provide evidence for establishment of the outer limits of the continental shelf beyond 200 nautical miles under article 76 of the UN Convention on the Law of the Sea as determination of the foot of slope and 2,500m isobath. Since the Multi-beam echo sounding data in large area are enormous, an efficient processing tool is necessary to deal with such data. So we developed new multi-beam data processing softwares.

Summary of the Bathymetry around Japan

Around Japan, four plates get together. Those four plates are Pacific Plate, Philippine Sea Plate, Eurasian Plate (or Amurian Plate) and North American Plate. Their subduction or collision forms complicated Japanese topography and bathymetry (Figure 1).

In the eastern area of Japan, four trenches line up. From the north, they are named Kuril Trench, Japan Trench and Izu-Ogasawara Trench. The subduction of Pacific Plate forms these trenches. The deepest point in Japan is 9,780m deep within Izu-Ogasawara Trench. Behind trenches, a set of many active volcanoes runs paralleled to trenches. It is an island arc, named Shichito-Iou Ridge. Behind the ridge, there is wide Shikoku Basin formed by back arc spreading of Pacific Plate. Behind the Shikoku Basin, Kyushu Palau Ridge extends from north to south. It is a remnant arc before back arc spreading of Shikoku Basin. Its origin is the same as Shichito-Iou Ridge. In the south area from Japan Islands, Nankai Trough expands about from east to west, and in east area from Okinawa, Ryukyu Trench expands from northeast to southwest. The subduction of Philippine Sea Plate from southeast forms those trough and trench. Behind the Ryukyu Trench, Ryukyu Ridge runs parallel to the trench. It is an island arc of Philippine Sea Plate. Between Kyushu Palau Ridge and Ryukyu Trench, there are 3 heights. From north, they are named Amami Plateau, Daito Ridge and Oki Daito Ridge. These are considered as remnant arcs.

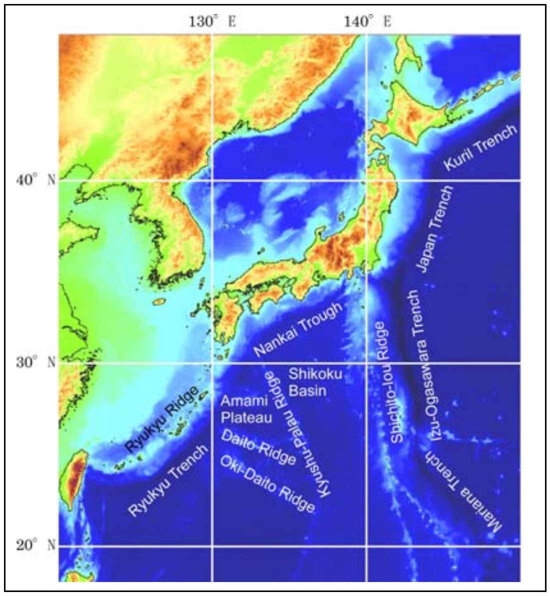

Figure 1: The Bathymetry around Japan. Data source is JTOPO30. JTOPO30 was compiled by Marine Information Research Center.

Multi-beam Survey Outline and Post-Processing Procedure

How is such a detailed bathymetry provided? Multi-beam Echo Sounder such as SeaBeam 2112 provides detailed depth measurements. In multi-beam survey, acquired data are shown in Table 1.

Table 1: Types of Acquired Multi-beam Survey Data

Data Type	Equipment	Description
Depth	Multi-beam Echo Sounder	151 reflected beams are received at the same time (SeaBeam2112). Depth measurements in wide area are acquired by shooting sound waves continuously.
Survey Vessel Position	GPS	
Pitch, Roll, Heave	Motion Sensor	
Ship Direction	Gyro Compass	
Vertical Profile of Acoustic Velocity	XBT or XCTD or S.V. Sensor	Every morning this is measured.

These raw data and corrected depths are recorded automatically.

In post processing, at first the format of depth measurement is converted to ping data. Ping data format is our data format. Many types of multi-beam data format can be converted to this ping format. So our softwares can be applied for many type of multi-beam data. Ping data are corrected more precisely by sound velocity in water. Next spurious depth measurements are cut as noises. Grid data are generated based on corrected ping data and interpolated. The quality of generated grids is checked. Thus detailed bathymetry chart are provided. In this paper, three characteristic post processing softwares are introduced in details. One is noise cut software, next gridding software, finally software for quality assessment of grid.

Noise Cut Filtering Software

Conventional method to filter noise is mainly manual operation with a mouse. But it takes a long time, because of enormous amount of multi-beam data. Therefore we developed automatic noise cut filtering software. The purpose of this software is to increase efficiency of noise cut filtering by automation. Our software models surface as bathymetry based on ping data and filters data much far from the surface. The procedure of automated cut filtering is shown as follows.

- Cell size setting by user (Cell: a surface unit)
- Modeling of each surface
- Setting of a threshold of residual value by user
- Cut filtering based on each residual value

General method to estimate surface is Least Squares Estimation. But with this method, a large error data causes abnormal surface, because surface follows all data equally (Figure 2). On the other hand, our software method is Robust Estimation. Surface is modeled by Weighted Least Squares Estimation. Each data's weight is in inverse proportion to the residual value of each depth measurement. Calculation is repeated until converging the surface. So larger residual value data are less influential to model surface. Even if there is a large error data, Robust Estimation can model normal surface (Figure 2).

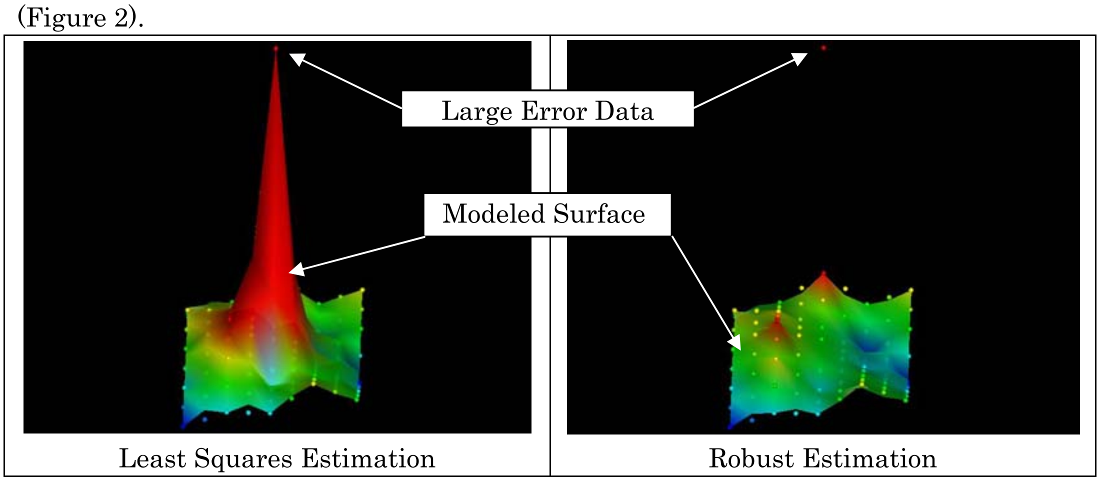

Figure 2: The comparison of concepts between Least Squares Estimation and Robust Estimation. The left is surfaces by Least Squares Estimation and the right is by Robust Estimation. With Least Squares Estimation, error data forms abnormal surface. On the other hand, with Robust Estimation, error data has little influence on modeled surface.

The effect of automated cut filtering was tested with survey data. The survey data information and parameters are shown in Table 2. Parameters must be decided by trial and error based on filtering results and the best parameters depend on bathymetry, depth, objects and purpose.

Table 2: Survey Data Information and Parameters

Data Information	Average Depth	About 5,800m
	Distance Between Beams	About 100m at swath center
		About 250m at swath edge
Parameter	Cell Size	800m
	Threshold of Residual Value	40m

Results are shown in Figure 3. Red cross marks are filtered data. In the top of Figure 3, some noises are filtered well. In the middle, many small noises are filtered well. And most of measurements on the small height are not filtered. In the bottom, some measurements on the height with steep slope are also filtered. As same as Least Square Estimation, the cutting method with Robust Estimation also filters some normal measurements as noise around depth changing point.

Before Cut Filtering | After Cut Filtering

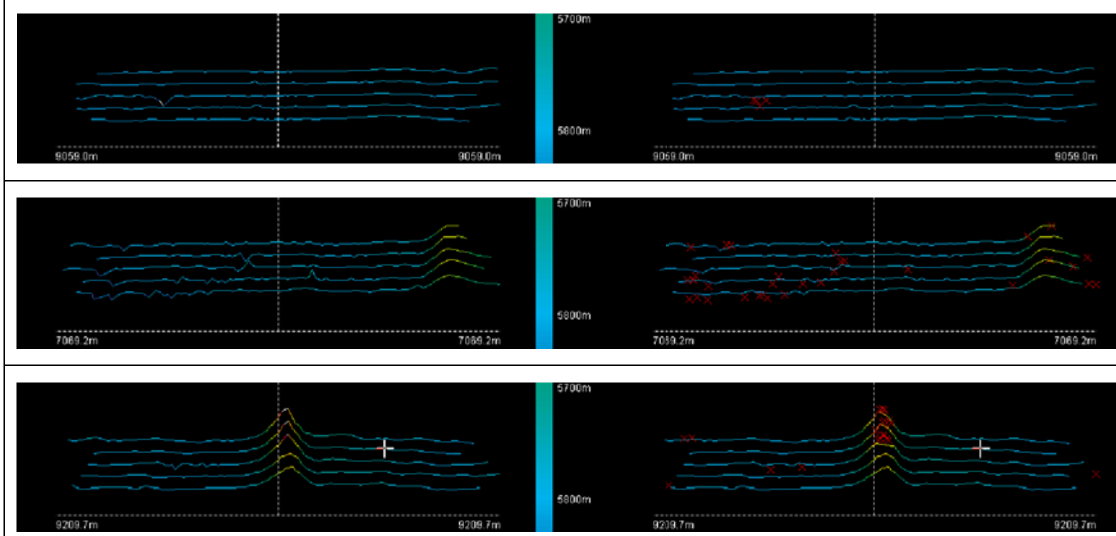

Figure 3: Results by automated noise cut filtering with survey data. These are enlarged 3D views. Red crosses are cut data. Noises are well cut.

Gridding Software

Conventional gridding software uses the interpolation method extensively beyond necessity, because beams are considered point data (Figure 4-Left). But actually each beam spreads and measures depth in foot print (Figure 4-Right). Foot print is a projected area of a spreading beam on seafloor. Because a beam measures depth in the foot print, it is considered that grids on the foot print can be generated, and this software generates grids by this logic. Because red grid in Figure 4 is based on depth measurement the same as green grid, red grid depth is as well grounded as green grid.

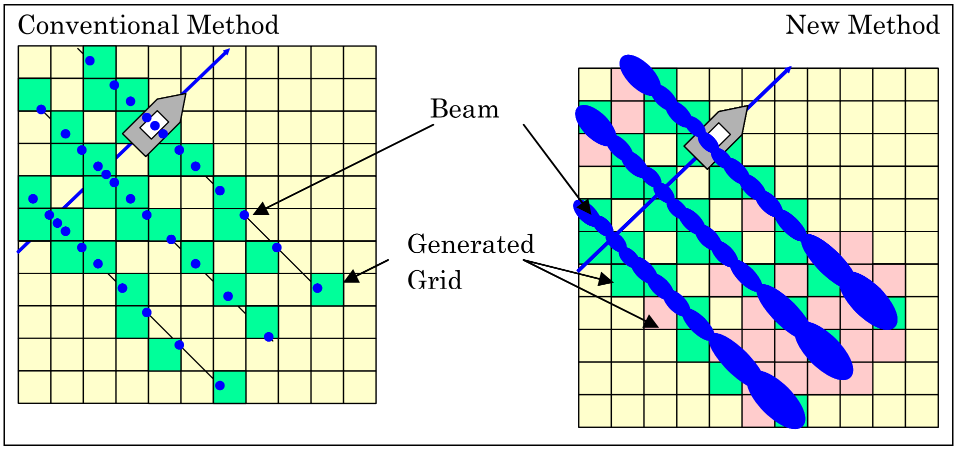

Figure 4: The comparison of concepts between conventional gridding method and the new gridding method. The left is conventional method and the right is new method. Blue points and blue ellipses mean beams. Green grids mean common generated grids in both methods. Red grids mean generated grids in only new method.

Grid depth is calculated by weighted average method. Weight of each spreading beam is calculated as a total of probability density of overlapping area with grid. The probability density is defined as the probability that sonic wave in a foot print arrives first at the sonar. The first arrival sonic wave is acquired as depth of the beam.

The result by new gridding method is compared with the result by conventional gridding method in Figure 5. Real multi beam data are applied. Depth range of the data is between 4,600m and 7,000m. Grid size is set 5”. It is nearly equal to 150m. Grid data are not interpolated. According to comparison of results, little interpolation is necessary in the new method.

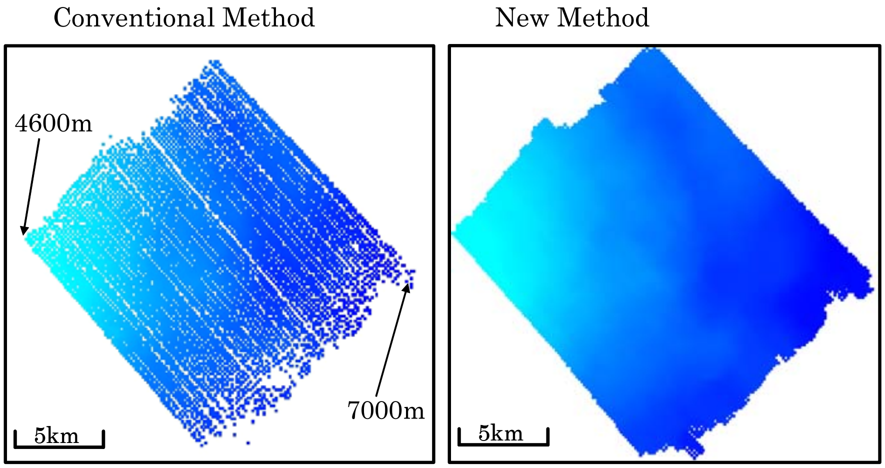

Figure 5: The comparison of two gridding results without interpolation. The left is the result by conventional method, and the right is the result by new method. Cyan grid is shallower grid, and oriental blue grid is deeper grid. In new method, little interpolation is necessary.

Next the result by new gridding method is compared with the result by conventional gridding method in narrower area with survey data in Figure 6. Depth range of data is between 2,050m and 2,700m. Grid size is set 3". It is nearly equal to 90m. Grid data are not interpolated. Detailed bathymetry by new method matches with conventional method. For example, ridge in left of Figure 6 matches with ridge in right of Figure 6.

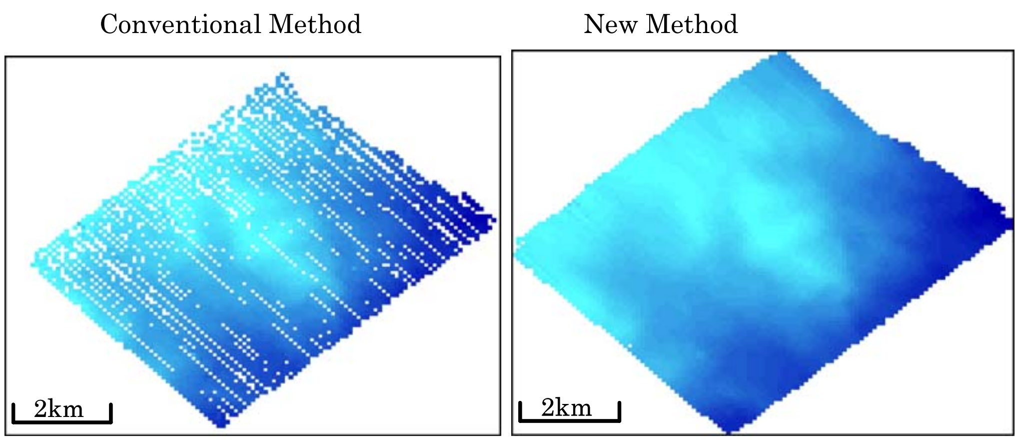

Figure 6: The comparison of gridding results by two methods, without interpolation. Ridges and channels match in both methods.

Software for Quality Assessment of Grid

Depth of grid is calculated by average or weighted average based on ping data, and there are some interpolated grids in grid data. So grid data are less grounded than ping data, and the reliability also decreases. Reliability of grid data must be checked. The purpose of this software is quality assessment of grid data.

The method of quality assessment of grid data is overlaying grid data with ping data in 2D or 3D view. 2D view proves how many beams participate in each grid. 3D view proves the difference between grid depth and beam depths. For example, this software suggests whether height of grid in small area is a remained noise or not. If beam density is much lower than grid density, it may be noise. Even if beam density is high, if the deference between beam depths around height is large, it may be noise.

For example, does the hollow in the left of Figure 7 actually exist? In the middle of Figure 7, many beams have influence in forming the hollow. But the right of Figure 7 suggests that two beams have influence in forming the hollow largely. And because depths of two beams are far from depths of others, these may be noise. So it is important to check two beams again.

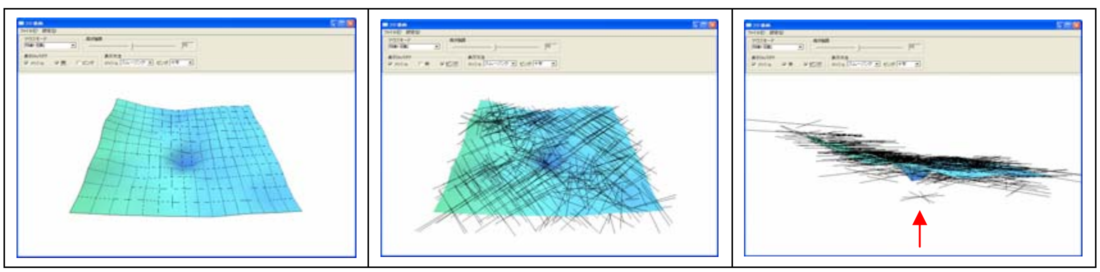

Figure 7: Overlaying grid data and ping data. In the left, grids are plotted in 3D view. In the middle, beams are overlaid with grids. A beam is displayed as cross. The cross shows long and short radius of a foot print. In the right, view angle are changed. Two beams are far from others. And these form the hollow.

Conclusions

- Multi-beam data processing softwares were developed.
- Operating efficiency was improved by increasing automation of noise cut filtering processing.
- Interpolated grids reduced compared with conventional software.
- Quality of grid data could be assessed by overlaying grid with beam on the display.