자원환경지질, 제39권, 제3호, 229-234, 2006
Econ. Environ. Geol., 39(3), 229-234, 2006

EZXover: C program to Reduce Cross-over Errors in Marine Geophysical Survey Data

Moo-Hee Kang*, Hyun-Chul Han, Kyong-O Kim, Don Sunwoo, Jin-Ho Kim and Gee-Soo Gong

Petroleum and Marine Resources Research Division, Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, Korea

지구물리탐사자료에서 교차점오차를 보정하기위한 EZXover 프로그램 개발

강무희* · 한현철 · 김경오 · 선우돈 · 김진호 · 공기수

한국지질자원연구원 석유해저자원연구부

일반적으로 자료를 해석할 때 교차점오차 (cross-over error: XOE)에 의하여 종종 오류를 범할 수 있다. 그러나 이러한 교차점오차에 의한 오류는 두개의 교차점 (cross-over point: XOP) 사이의 자료를 비율적으로 보정하여 제거할 수 있다. 본 연구에서 빠른 기각테스트 (quick rejection test)와 걸침테스트 (straddle test)를 통하여 교차점을 계산하고 가중치선형내삽 알고리즘 (weighted linear interpolation algorithm)을 이용하여 교차점오차를 보정하는 프로그램을 C 프로그래밍 언어로 작성하였다.

주요어 : 교차점오차, 빠른 기각테스트, 걸침테스트, 연결리스트, 가중치선형내삽

Cross-over errors (XOEs) may mislead scientists when interpreting marine geophysical data. Such risk can be reduced by correcting the data proportionally between two cross-over points (XOPs). C program is presented to determine XOPs using a quick rejection test and a straddle test, and to adjust XOEs using a weighted linear interpolation algorithm.

Key words : Cross-over error, Quick rejection test, Straddle test, Linked list, Weighted linear interpolation

1. INTRODUCTION

Marine geophysical data including bathymetric, gravity, and magnetic data usually show different values at their cross-over points (XOPs). These discrepancies, called cross-over errors (XOEs), are caused by various factors such as quality of navigation, instrument drift, diurnal variation, inaccurate Eötvös correction, etc (Fig. 1). If XOEs are greater than the anticipated temporal variation, it can mislead the data interpretation. Therefore, many scientists (Johnson, 1971; Sander and Mrazek, 1982; Prince and Forsyth, 1984; Tai, 1988; Wessel and Watts. 1988; Wessel, 1989) have proposed to minimize XOEs. Most works, however, do not provide a unique solution for any given dataset, but apply to a specific dataset. It implies that there are many different methods depending on various types of surveys and geometries of survey lines. One of those is a block overlapping technique to find cross-over points in any given dataset, and values at XOPs are interpolated using a quasi-hermite spline (Akima, 1972) proposed by Wessel (1989). This method, however, does not completely remove XOEs, and an additional technique to smooth out the residual XOEs was required. For this purpose, Hsu (1995) introduced a coordinate system transformation method to find XOPs and correct XOEs using a linear interpolation algorithm (Mittal, 1984). Although this method can accurately identify XOPs and remove residual XOEs, it is complicated with limited flexibility.

This study introduces a new and very simple

*Corresponding author: karl@rock25t.kigam.re.kr

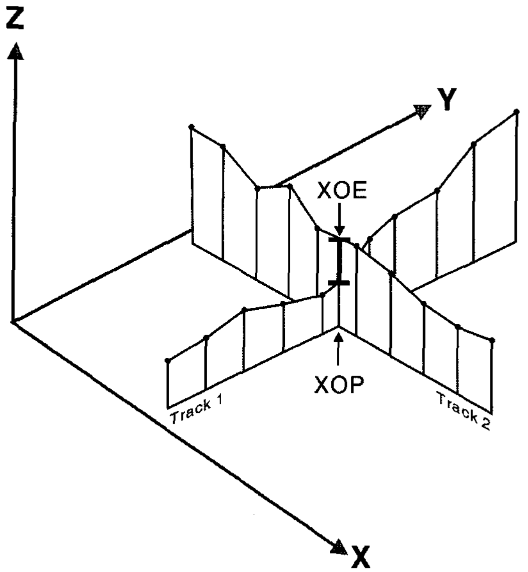

Fig. 1. Schematic diagram showing cross-over error (XOE) at one cross-over point (XOP) from two track lines (after Wessel and Watts, 1988).

method called a straddle test that uses a line intercepting algorithm and a linear equation to find all XOPs in any given dataset, and Mittal's algorithm (1984) was then adopted to correct and smooth the XOEs. Also, to effectively control computer memories and manage the data, a linked list algorithm was implemented instead of assigning a dimension of each I/O parameter.

2. METHODS

A linear line connecting two neighboring points (A (X1, Y1), B (X2, Y2)) in a track was assigned as a reference segment, and the remaining two points (C (X3, Y3), D (X4, Y4)) in the other track were also assigned as a comparing segment to test whether the cross-over point locates between these two segments (Fig. 2). A two-step process is generally used to determine whether the two lines intersect; quick rejection test and straddle test (Loudon, 1999). It is claimed that two segments intersect each other only when both tests succeed. To perform a quick rejection test, a bounding box needs to be constructed around each line segment (Fig. 2a). If the two bounding boxes do not overlap, it implies that there is no cross-over point between two segments. The straddle test may then be skipped to move on to the next segment for conducting another quick rejection test. If passed, however, the straddle test proceeds as the next step. A straddle test is to compare the orientation of C relative to B with that of D relative to B (Fig. 2). Each point's orientation shows whether the point is clockwise or counterclockwise from B with respect to A. The following equations are used to determine the orientation of C relative to B with respect to A (Z1), and to determine the orientation of D relative to B with respect to A (Z2):

$$Z1 = (X3-X1)(Y2-Y1) - (Y3-Y1)(X2-X1)$$
$$Z2 = (X4-X1)(Y2-Y1) - (Y4-Y1)(X2-X1)$$

Based on the above equation, Loudon (1999) proposed several criteria to determine whether the two line segments intersect. For instance, if Z1 is positive, C is clockwise from B, and if it is negative, C is counterclockwise from B. If it is 0, the point is on the same imaginary line extending from A. The same interpretation also applies to Z2. Similarly, if the signs of Z1 and Z2 are the same (Fig. 2b), two segments do not intersect, and if the signs of Z1 and Z2 are different (Fig. 2c), or if either is 0 (Fig. 2d), it is implied that two line segments intersect. These criteria, however, have a few shortcomings that limit their suitability for marine geophysical datasets, which are composed of many XOPs rather than a line segment with minimum and maximum values. For examples, when D is out of range of the reference segment, but lies on or above the imaginary line (Figs. 2e and 2f), the quick rejection and straddle tests will show that the two segments intersect even though they do not cross each other. These cases, which frequently occur in marine geophysical data, should be eliminated to avoid improper XOPs. One of the easiest ways to resolve these problems is to do an additional straddle test with the opposite assignment for the initial line segment: C and D as the reference segment, and A and B as the comparing segment. The following equations determine the orientation of A relative to D with respect to C (Z3), and the orientation of B relative to D with respect to C (Z4):

$$Z3 = (X1-X3)(Y4-Y3) - (Y1-Y3)(X4-X3)$$
$$Z4 = (X2-X3)(Y4-Y3) - (Y2-Y3)(X4-X3)$$

The signs of Z3 and Z4 will determine whether the

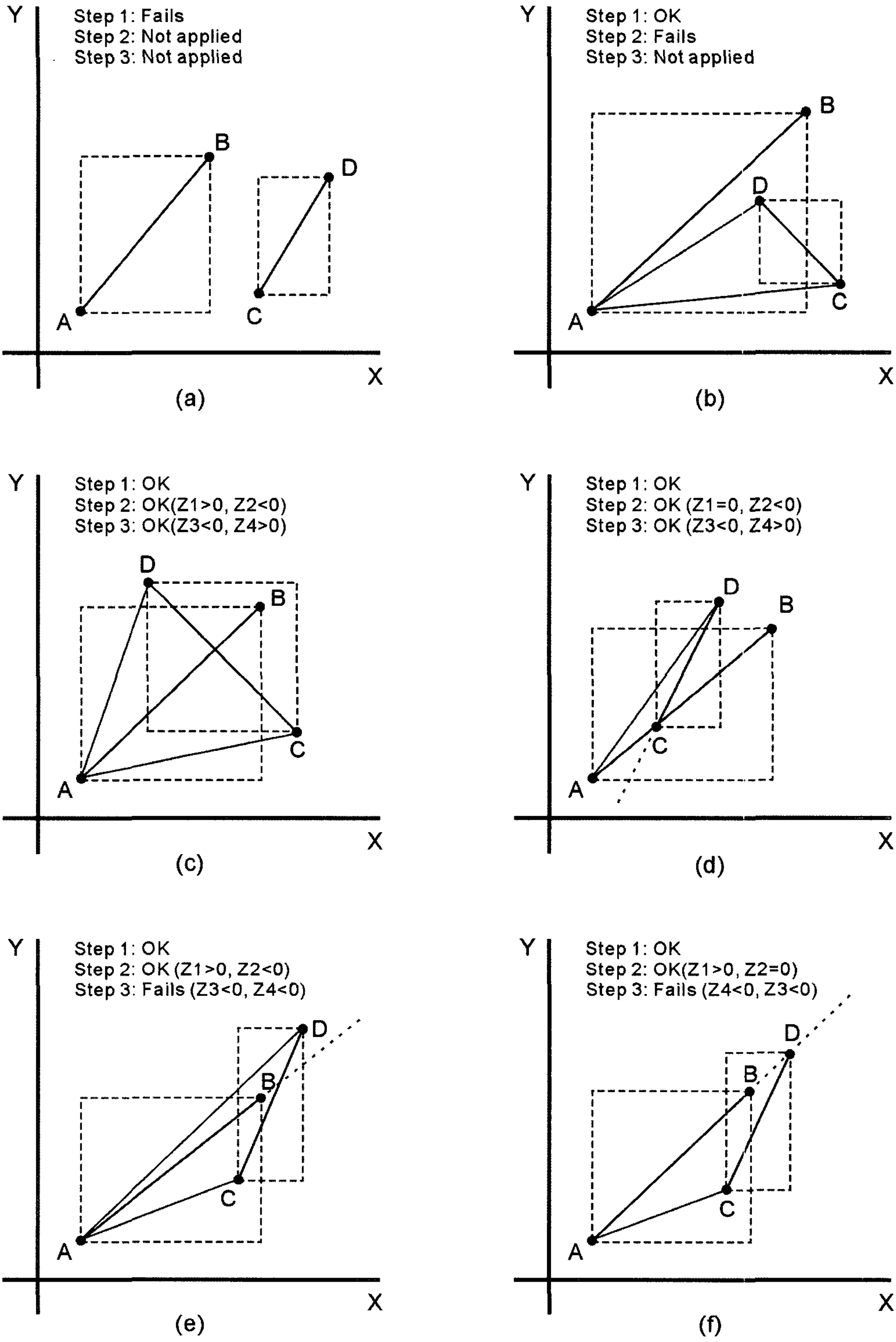

Fig. 2. Schematic diagrams showing whether the line segments intersect using a quick rejection test (step 1) and a straddle test (step 2 and step 3).

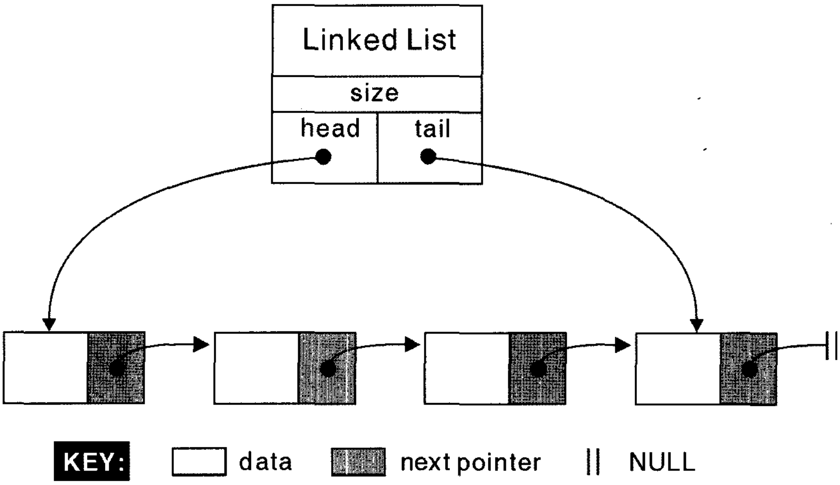

Fig. 3. Block diagrams illustrating elements linked together to form a linked list (after Loudon, 1999).

two line segments intersect according to the same criteria as mentioned above. The results for the point lying on or above the imaginary line, which is out of range of the reference segment, showed that there were no intersecting points. These results further suggest that two segments can be claimed to intersect only when the straddle test succeeds twice after first passing quick rejection test.

When the intersecting line segments are detected, the coordinate of XOP needs to be calculated to correct the XOEs. A simple equation for a linear line as follows was used to calculate XOP coordinate.

$$Y - Y1 = (Y2-Y1)/(X2-X1)(X-X1), \text{ if } X1 \neq X2$$
$$Y - Y3 = (Y4-Y3)/(X4-X3)(X-X3), \text{ if } X3 \neq X4$$

where X and Y with subscriptions denotes the coordinates of the end points of each line segment. After XOP coordinates are calculated, XOEs at XOP are expected and needs to be corrected to avoid any wrong perception to interpret the data. Mittal's linear interpolation algorithm (1984) was used to calculate weighting values for each track line and mean weighting values for all track lines. Also, the weighted average values for all XOPs were obtained from the following equation and a linear interpolation proportional to the distance of each XOP was conducted to correct XOEs:

$$g_{ij} = \frac{g_i W_i^* + g_j W_j^*}{W_i^* + W_j^*}$$

where g_i is the interpolated value for the XOP at the *i*th track, and g_j is the interpolated value for the same XOP at the *j*th track. g_{ij} is the adjusted value at the same XOP computed from g_i and g_j. W_i^* and W_j^* are the mean weighted levels of unity which are computed from the relative weights of the *i*th and the *j*th track, respectively.

All processes mentioned above can be managed in most modern computers. However, if a large amount of data needs to be handled, or if computer memory is too small, it may cause a problem. In general, arrays of data are used to control memory in Fortran or C programs. In this case, however, the maximum size of data is limited to the size of the given dimension of I/O parameters, or the

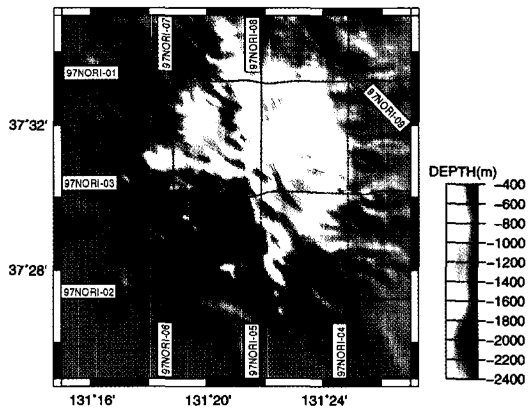

Fig. 4. Gravity track lines around the Ulleung seamount, East Sea, obtained from NORI (1997).

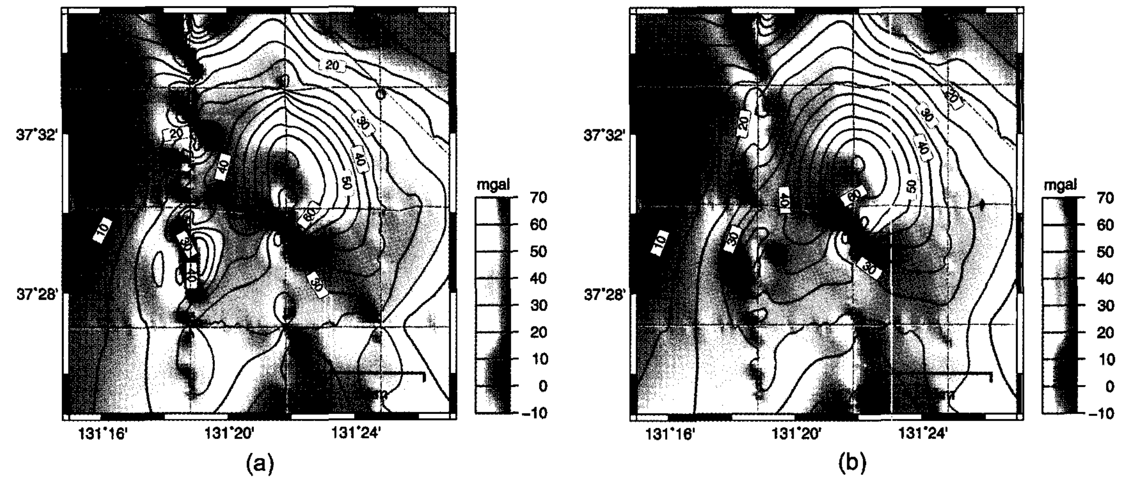

Fig. 5. Numerical examples showing XOEs before (a) and after (b) implementing the EZXover program.

Table 1. EZXover results showing XOEs and other related values.

xcoord	ycoord	XOE	RefLine	RefCnt	RefVal	CmpLine	CmpCnt	CmpVal	WAveVal
131.414627	37.552922	-1.5	97NORI-01	58	19.7	97NORI-09	2128	21.2	21.1
131.414143	37.552903	1.2	97NORI-01	59	19.8	97NORI-04	1131	18.6	18.9
131.364128	37.552328	-9.0	97NORI-01	160	32.0	97NORI-08	1977	41.0	36.9
131.314152	37.552846	14.1	97NORI-01	262	24.5	97NORI-07	1701	10.4	16.6
131.313972	37.552846	8.5	97NORI-01	263	24.4	97NORI-06	1485	16.0	19.7
131.414122	37.452832	-8.8	97NORI-02	426	21.1	97NORI-04	1266	29.9	27.5
131.364118	37.452973	8.6	97NORI-02	520	26.6	97NORI-05	1379	18.0	22.5
131.314160	37.452868	-7.1	97NORI-02	618	23.8	97NORI-06	1615	30.9	27.7
131.314175	37.502767	-12.6	97NORI-03	827	28.1	97NORI-06	1554	40.7	34.6
131.314185	37.502766	-6.0	97NORI-03	827	28.1	97NORI-07	1779	34.1	31.2
131.364276	37.501354	6.0	97NORI-03	920	59.0	97NORI-08	1858	53.0	56.0
131.414153	37.501724	2.9	97NORI-03	1022	37.0	97NORI-04	1199	34.1	34.9
131.414144	37.553314	-3.1	97NORI-04	1130	18.0	97NORI-09	2128	21.1	20.5
131.314096	37.569578	8.7	97NORI-06	1460	12.6	97NORI-07	1679	3.9	8.3
131.314184	37.556898	3.0	97NORI-06	1480	13.2	97NORI-07	1694	10.2	11.7
131.314139	37.544685	10.3	97NORI-06	1497	24.1	97NORI-07	1712	13.8	19.0
131.314133	37.543960	9.6	97NORI-06	1498	24.3	97NORI-07	1713	14.7	19.5
131.314140	37.543876	9.5	97NORI-06	1499	24.2	97NORI-07	1713	14.7	19.4
131.314237	37.535823	7.8	97NORI-06	1511	24.9	97NORI-07	1726	17.1	21.0
131.314230	37.535012	6.3	97NORI-06	1511	23.9	97NORI-07	1727	17.6	20.7
131.314226	37.534518	6.3	97NORI-06	1512	23.9	97NORI-07	1728	17.6	20.8
131.314222	37.534069	7.0	97NORI-06	1513	24.5	97NORI-07	1729	17.5	21.0
131.314209	37.532610	7.1	97NORI-06	1516	26.2	97NORI-07	1731	19.1	22.7
131.314147	37.522150	6.9	97NORI-06	1530	32.0	97NORI-07	1747	25.1	28.6
131.314098	37.519480	7.8	97NORI-06	1533	33.0	97NORI-07	1751	25.2	29.1
131.314108	37.507080	5.1	97NORI-06	1551	38.0	97NORI-07	1771	33.0	35.5
131.314153	37.505803	5.0	97NORI-06	1552	39.0	97NORI-07	1773	34.0	36.5
131.314181	37.502365	5.9	97NORI-06	1555	40.6	97NORI-07	1779	34.7	37.7
131.314165	37.500516	3.7	97NORI-06	1557	38.7	97NORI-07	1782	35.0	36.8
131.314036	37.491991	8.2	97NORI-06	1568	46.0	97NORI-07	1796	37.8	41.9
131.314078	37.490419	5.2	97NORI-06	1569	43.2	97NORI-07	1797	38.0	40.6
131.314078	37.490303	5.0	97NORI-06	1570	43.0	97NORI-07	1798	38.0	40.5

Before Correct : Num of XOPs = 32, Mean XOE = 3.8, RMS XOE = 7.4, Max XOE = 14.1, Min XOE = 1.2

After Correct : Num of XOPs = 32, Mean XOE = -0.1, RMS XOE = 1.2, Max XOE = -5.9, Min XOE = -0.0

RefLine, reference line; RefCnt, data number of reference line at the XOP; RefVal, data values of reference line at the XOP; CmpLine, comparing line; CmpCnt, data number of comparing line at the XOP; CmpVal, data values of comparing line at the XOP; WAveVal, weighted average values at the XOP.

memory size is over allocated if the assigned dimension is much larger than the actual size of data. Therefore, a linked list algorithm (Loudon, 1999) was adopted for this study to efficiently use the memory. Linked lists are composed of individual elements linked by a pointer. Each element consists of a data member and a pointer. Using this two-member structure, a linked list is formed by setting the next pointer of each element to point to the element that follows it (Fig. 3). The next pointer of the last element is set to null denoting the end of the list. The element at the start of the list is its head and the element at the end of the list is its tail. To access an element in a linked list, the head of the list starts and uses the next pointers of successive elements to move from element to element until the desired element is reached. Since linked lists allocate the memory space dynamically, it only requires a small amount of memory size. This method was also applied to do a statistical analysis of data, and to provide the information of XOEs and weighting values.

3. NUMERICAL EXAMPLES

To examine the validity and efficiency of the developed algorithm and program, EZXover program was tested with the Free-Air gravity data obtained over a seamount in the East Sea, Korea. The data was collected by NORI (Korea National Oceanographic Research Institute) in 1997, and was composed of 9 track lines with 5 NS, 3 EW, and 1 NW-SE direction (Fig. 4). Line numbers 6 and 7, and 5 and 8 were surveyed on the same track, respectively. Before employing the EZXover program, all corrections such as drift and Eötvös were already applied to make a Free-Air anomaly map around the seamount. The contour map with a 5 mgal interval was drawn using GMT (Wessel and Smith, 2004). As shown in Fig. 5a, pseudo-structures or severe distortions caused by XOEs are easily identified along the track lines 6 and 7. After applying the EZXover program, however, most XOEs were smoothed out and a reliable contour map was obtained (Fig. 5b). The calculated XOEs at the XOPs and the other related values were shown in Table 1.

ACKNOWLEDGMENTS

This work was supported by the grant 05-9106 from MOMAF Research Fund. We thank Mr. Se-Yeol Hwang of NORI who provided the gravity data. We appreciate the valuable comments made by reviewers, which helped us greatly to improve this paper.

REFERENCES

Hsu, S.K. (1995) XCORR: A cross-over techniques to adjust track data. Computer & Geosciences, v. 21, p. 259-271.

Johnson, R.H. (1971) Reduction of Discrepancies at Crossing Points in Geophysical Surveys. Jour. Geophys. Res., v. 76, p. 4892-4896.

Loudon, K. (1999) Mastering algorithms with C. O'Reilly & Associates, Inc., CA, 540p.

Mittal, P.K. (1984) Algorithm for error adjustment of potential field data along a survey network. Geophysics, v. 49, p. 467-469.

Prince, R.A. and Forsyth, D.W. (1984) A simple objective method for minimizing crossover errors in marine gravity data. Geophysics, v. 49, p. 1070-1083.

Sander, E.L. and Mrazek, C.P. (1982) Regression technique to remove temporal variation from geomagnetic survey data. Geophysics, v. 47, p. 1437-1443.

Tai, C.K. (1988) Geosat crossover analysis in tropical pacific 1. Constrained sinusoidal crossover adjustment. Jour. Geophys. Res., v. 93, p. 10621-10629.

Wessel, P. (1989) XOVER: a cross-over error detector for the track data. Computer & Geosciences, v. 15, p. 333-346.

Wessel, P. and Smith, W.H.F. (2004) GMT Version 4 Technical Reference and Cookbook. The Generic Mapping Tools, 123p..

Wessel, P. and Watts, A.B. (1988) On the accuracy of marine gravity measurements. Jour. Geophys. Res., v. 93, p. 393-413.

2006년 1월 26일 원고접수, 2006년 6월 20일 게재승인.