Seabed Topographic Contour Match Based on Angle Code Technique

Hongmei Zhang
Automation Department
Wuhan University
Wuhan, China, 430072

Jianhu Zhao
School of Geodesy and Geomatics
Wuhan University
Wuhan, China, 430079

Kun Yang Chunhe Tian
Tianjin Research Institute for
Water Transport Engineering
Tianjin, China, 300456

***Abstract*-Seabed topographic match is a very important work for fulfilling the blend of different-source sounding data and the underwater positioning and navigation. Contour match is a classic method for the seabed topographic match. However, the traditional contour match algorithm will lead to obvious time consuming and mismatch, especially in the longer contour match. Thus, a kind of contour match algorithm based on angle code technique is presented and studied in this paper. Firstly, the principle of this match method is detailed. Then some key problems are studied, and the matching procedure is given out. Besides, the method was used for a simulation experiment of underwater topographic matching navigation, the satisfying results are achieved.**

I. INTRODUCTION

Seabed topographic match is a very important work for fulfilling the blend of different-source sounding data and implementing the underwater positioning and navigation[1][2][3][4]. Seabed topography can be acquired by multibeam bathymetric system and single-beam sounding system, by means of the match, the topographic information can be blended together. Besides, inshore seabed has rich feature information, which provides the possibility for the underwater independent navigation based on seabed topographic match [5][6][7]. The contour match is a classic method for the seabed topographic match. BEHROOZ KAMGAR-PARSI et al.(1989) studied the contour matching algorithm based on chain code technique, which assumes that the contour is laid on a grid, and the grid where contour passes is marked as 1, otherwise marked as 0. Thus, the contour is expressed with these marked grids in the form of chain code. The method depicts in detail the contour in a grid, while the whole contour orientation is not reflected well [8], and thus results in obvious time consuming and mismatch at some time, especially in longer contour match. In order to improve this method, the paper studies and gives out a kind of contour match algorithm based on angle code technique.

II. ANGLE CODE TECHNIQUE

First of all, the grid at the given resolution, which covers the whole studied area, is designed. For a contour, the orientation of the contour is depicted with the horizontal angle α in the contour-pass grid. For the two adjacent grids, the direction of the contour can be expressed with the angle difference β,

$$\alpha_{\mathrm{i}} = tg^{-1}\frac{\Delta x}{\Delta y} = tg^{-1}\frac{(x_{i+1}-x_i)}{(y_{i+1}-y_i)} \qquad (1)$$
$$\beta_{\mathrm{i}} = \alpha_{\mathrm{i+1}} - \alpha_{\mathrm{i}}$$

where, α_i and α_{i+1} are the horizontal angle of the contour at i^{th} grid and $i+1^{th}$ grid; (x_i, y_i) and (x_{i+1}, y_{i+1}) are the coordinates of the intersection points of contour passing the upper side and the lower side in the i^{th} grid respectively.

By the above code, i^{th} grid and $i+1^{th}$ grid are connected together. Similarly, for other adjacent contour-pass grids, the code work is also done. By this way, the whole contour is expressed by $\{\beta_i, i=1, 2, 3, \ldots, n-1\}$.

III. CONTOUR MATCH METHOD BASED ON ANGLE CODE

If there exists two data sources, such as the reference field (1) and the matching field (surveying seabed) (2), for a matched contour, at least two corresponding data sets with the same contour value, such as $\{\beta_1(i), i=1, 2, 3, \ldots, n\}$ in the reference filed and $\{\beta_2(i), i=1, 2, 3, \ldots, m\}$ $(n>m)$ at the matching field, can be found. For one of the contour pairs, the matching contour is moved along the reference contour, the angle bias T can be calculated at each of moves.

$$T(k) = \sum_{i=1}^{m}(\beta_1(i+k)-\beta_2(i))^2 \qquad (2)$$
$$i = 1,2,\cdots m;\quad k = n-m+1$$

Finishing above moves, the minimum angle bias T can be acquired.

$$T = Min\{T(k), k = n-m+1\} \qquad (3)$$

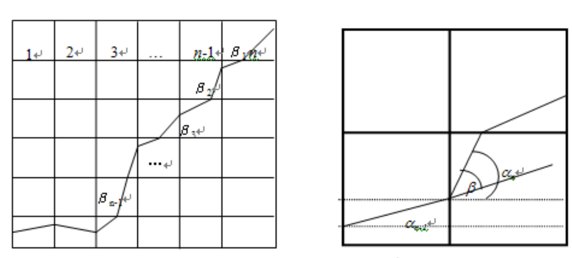

Figure 1. Depiction of the contour

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Other contour pairs with the same contour value may be found. Similar work can also be done. Comparing these *Ts*, the minimum *T* and the corresponding contour pair can be found further. If there is only coordinate translation ΔX between the reference field and the matching field, X_M is the coordinates of matching points in the matching field, the corresponding one in the reference field is X_R. ΔX can be calculated by the matching pair with the minimum *T*.

$$\Delta X = X_M - X_R \tag{4}$$

If both the coordinate translation ΔX and rotation exist between the two fields, an angle bias $\Delta\overline{T}$ needs to be considered in the match. The following matching ruler should be abided by.

$$\begin{aligned} T(k) &= \sum_{i=1}^{m}(\beta_1(i+k)-\beta_2(i)-\Delta\overline{T})^2 \\ \Delta\overline{T}(k) &= \frac{1}{m}\sum_{i=1}^{m}(\beta_1(i+k)-\beta_2(i)) \end{aligned} \tag{5}$$

$T(k)$ in (5) reflects the similarity of two series at k^{th} matching, which has the similar meaning as mean square of root (RMS), and depicts the scatter degree.

After finishing a matching for some contours, the rotation angle $\Delta\overline{T}(k)$ can be got. The rotation matrix is constructed using the angle, and the observation coordinate can be transferred by the matrix.

$$\begin{pmatrix} x' \\ y' \end{pmatrix}_s = R(\Delta\overline{T}(k))\begin{pmatrix} x \\ y \end{pmatrix}_s \tag{6}$$

Then, according to the coordinates of each point at matching series and its corresponding coordinate in the background, the difference (Δx, Δy) between them can be determined.

$$\begin{aligned} \Delta x &= x_s' - x_{BG} \\ \Delta y &= y_s' - y_{BG} \end{aligned} \tag{7}$$

Actually, $\Delta\overline{T}(k)$ and (Δx, Δy) reflect the relationship of rotation and translation, which is produced by INS error accumulation. Thus, (Δx, Δy) is also INS error accumulation, and $\Delta\overline{T}(k)$ is also the orientation angle bias of INS.

Multibeam bathymetric system can acquire real-time swath seabed topography. In the surveying area, there are *l* contours with different value. In order to acquire accurate INS error accumulation and angle bias, the *l* contours are used for matching processing. For each of contour matching, the corresponding translation (Δx, Δy) can be acquired. In the matching results, a quality control is implemented to eliminate the error matching influence. According to these translations, the mean translation and standard bias can be acquired.

$$\begin{aligned} \Delta x &= \frac{1}{l'}\sum_{i=1}^{l'}\Delta x_i \\ \Delta y &= \frac{1}{l'}\sum_{i=1}^{l'}\Delta y_i \qquad l' \le l \end{aligned} \tag{8}$$

$$\begin{aligned} \sigma &= \sqrt{\frac{[\Delta_i\Delta_i]}{l'-1}} \\ \Delta_i &= \Delta P - \Delta\overline{P} \\ \Delta\overline{P} &= \frac{1}{l'}\sum_{i=1}^{l'}\sqrt{(\Delta x_i^2 + \Delta y_i^2)} \end{aligned} \tag{9}$$

Where, ΔP is the positioning error.

Using 3σ as the threshold, we can find the abnormal translations from all of matching results.

IV. Study on Key Problems

In order to ensure the matching performance of above method, three key problems are studied.

Firstly, the choice of matching contours is discussed. Different-value contours may exist in the matching area. In theory, all contours for the match will improve the accuracy and reliability of the match. However it may bring obvious time consuming and the decrease of matching accuracy in some complex seabed. Thus it is necessary to choose the representative contours for the match.

Secondly, in order to eliminate mismatch in flat seabed and high-similarity seabed, the mismatch is also discussed. In order to eliminate mismatch, it is necessary to decrease the contour interval in drawing these contours so as to enhance the subtle topographic features. Besides, similar seabed can be found in the background, thus these areas should be avoided in the design of navigation track. Moreover, when the high-similarity seabed can not be avoided, longer matching area is needed for overcoming the matching indetermination.

Thirdly, the influences of data resolutions and data accuracy of the two fields for the match are analyzed. According to the experiments, both the topographic data of matching area and of background with the same scale can eliminate efficiently the influence of mismatch.

V. Matching Procedure

Seabed topographic matching positioning is chosen as the studied aim, a completed contour match procedure is given out.

Firstly, an approximate matching area is found by means of the positioning result of inertial navigation system (INS) in the reference field. Then, the contours in the reference field and the matching field are drawn and coded by the angle code technique. Furthermore, for each of the chosen contour value, the matching pairs can be found, and the matching process is done. Finally, according to the optimum matching pair, the coordinate translation and the rotation angle between the coordinate systems of the two fields can be determined.

Now, the match between the reference topography and the matching topography is fulfilled. By means of these parameters, the actual underwater vessel location is acquired.

VI. EXPERIMENT AND ANALYSIS

The method was used for a simulation experiment of underwater topographic matching navigation. The seabed with 5 km×5 km is chosen as the background. The accumulation error and initial orientation bias of INS are set as (-1000 m，-1000 m) and 2° respectively. Based on the above parameters, single-area matching and multi-area matching are done in the area.

In single-area matching experiment, a small area with 1000 m × 1000 m is chosen as the matching area in the background (see Fig. 2). According to the contour distribution, a contour is chosen as the characteristic contour. Based on the value of this contour, the 5 contours more than the value and another 5 contours less than the value are also chosen for the match. The matching result is shown in Table I.

In order to reflect the matching accuracy, a calculation for acquiring the standard bias σ of translation Δ*P* is done. The value of σ which equals ± 6.5 m can be gotten. Based on 3σ principle, the elimination of abnormal translation is done. Finally, the translation acquired by the match is 986.3 m at *x* direction and -991.5 m at *y* direction, and 1392.9 m for location. Integrated the pre- translation value (-1000 m，-1000 m), the single-area matching accuracy in the experiment is 13.7 m at *x* direction, 8.5 m at *y* direction and 16.6 m for location.

Another experiment, multi-area matching, is done in the same seabed. 6 small areas are chosen for the match. Each of the areas has the size of 500 m × 500 m. These areas are d along a 4.3 km track (Fig. 3). In the matching, according to the drift rate of INS, the accumulation error and initial angle bias can be thought to be a constant. The matching results of each small matching area are shown in Table II.

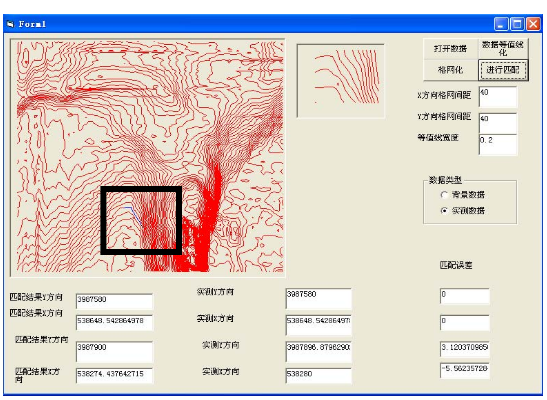

Figure 2. Single-area matching

TABLE I
MATCHING ACCURACY IN SINGLE BLOCK MATCHING EXPERIMENT

contour /m	Δx /m	Δy /m	Δ*P* /m	Δ*A* /°	*dx* /m	*dy* /m	*dP* /m
5	-987.6	-989.6	1398.1	1.82	12.4	10.4	16.2
4	-988.2	-984.4	1394.8	1.91	11.8	15.6	19.6
3	-985.4	-983.8	1392.4	1.85	14.6	16.2	21.8
2	-980.0	-990.1	1393.1	1.96	20.0	9.9	22.3
1	-985.4	-993.6	1399.4	1.96	14.6	6.4	15.9
0	-993.8	-996.8	1407.6	1.90	6.1	3.1	6.8
-1	-998.3	-1000.0	1413.0	1.91	1.7	0.0	1.7
-2	-984.8	-989.8	1396.3	1.83	15.2	10.2	18.3
-3	-980.7	-991.9	1394.9	1.96	19.3	8.1	20.9
-4	-982.3	-998.9	1401.0	1.80	17.7	1.1	17.7
-5	-982.4	-987.5	1392.9	1.88	17.6	12.4	21.5
mean	-986.3	-991.5	1398.5	1.89	13.7	8.5	16.6

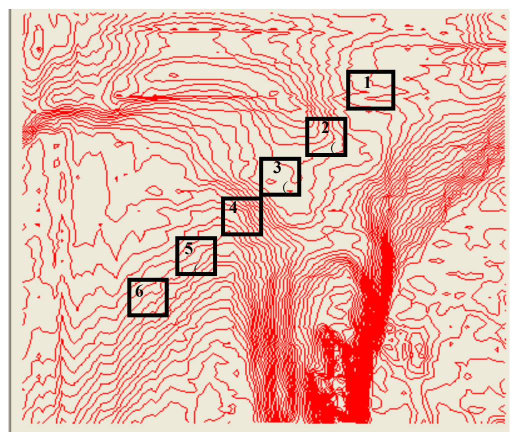

Figure 3. Continuous blocks

TABLE II
MATCHING ACCURACY IN MULTI-BLOCK EXPERIMENT

area	Δx /m	Δy /m	ΔP /m	ΔA /°	*dx* /m	*dy* /m	*dP* /m
1	-998.4	-1002.7	1415.0	1.92	1.6	-2.8	3.2
2	-999.6	-1004.7	1417.3	1.91	0.4	-4.7	4.7
3	-1292.5	-1242.0	1792.5	1.71	-292.5	-242.0	379.6
4	-998.6	-997.3	1411.3	1.91	1.4	2.7	3.0
5	-999.9	-1000.0	1414.1	1.93	6.3	0.0	6.3
6	-991.1	-984.0	1396.6	1.84	8.9	16.0	18.3
mean	-1046.7	-1038.5	1474.5	1.84	-45.7	-38.5	69.2
Mean 1	-1054.7	-997.7	1410.9	1.90	3.7	2.2	7.1
Mean 2	-999.1	-1001.2	1414.4	1.92	2.4	-1.2	4.3

According to the scatter degree of ΔP in Table II, the eliminating abnormal matching result is done firstly based on 3σ principle, and that the match in area 3 is thought to be mistake. Re-statistic work is done for these remain matching results after eliminating the mismatching area. The statistic result shows that the standard bias σ of positioning error ΔP is 3.7 m. Similarly, in virtue of 3σ principle, the abnormal matching result in area 6 is eliminated. After above processing, the remaining matching results from area 1, 2, 4 and 5 are used for statistics. Finally, the accuracy 2.4 m at x direction, 1.2 m at y direction, and 4.3 m for location are achieved.

Relative to the single-area match, the multi-area match decreases the size of single-area matching area. Depending on scatter degree of the different-area matching result, the mismatch problem can be found easily and eliminated. Thus the multi-area match method improves the accuracy of contour matching positioning.

VII. SUMMARIZATION

Due to rich information, local seabed topography matching navigation has better matching positioning accuracy than the single sequence match. The contour match based on angle-coded technique can fulfill the matching positioning in virtue of local seabed data. The method has been tested by actual experiments. We also hope it is improved further by experiments.

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