Study on the Underwater Geomagnetic Navigation Based on the Integration of TERCOM and K-means Clustering Algorithm

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***Abstract*- In order to improve the poor accuracy and stability of the traditional geomagnetic matching navigation by TERCOM， In this paper, we discuss a new method which is based on the integration of TERCOM, K-means clustering algorithm and INS (inertial navigation system) in detail. Through an experiment, we find that the new method has higher accuracy and stability than the traditional method, especially when it is used in the similar geomagnetic distribution area.**

I. INTRODUCTION

Underwater vehicle navigation technique is very important for the development and application of the underwater vehicle. Nowadays, in order to solve the error accumulation of inertial navigation system (INS), underwater geomagnetic matching navigation, which is a kind of independent navigation, becomes a hot research. The Geomagnetic is an important geophysics feature of the earth. Therefore, the geomagnetic matching navigation does not need any other external active signal. By means of geomagnetic matching navigation, the underwater vehicle can run safely and accurately.

In the geomagnetic matching navigation, the matching algorithm is very important. Traditionally, terrain contour matching (TERCOM) algorithm is used in the match positioning. Under ideal situation, this algorithm can obtain high accuracy and has fast speed in the matching positioning. However, the accuracy and stability will be worse when geomagnetic observation exits noise and the matching navigation carries out in the similar geomagnetic distribution area. Relative to TERCOM，K-Mean algorithm can cluster the data which has the similar property. These data can provide abundant observation values for improving the poor accuracy and high-probability mismatching of the TERCOM algorithm. Considering the matching speed of TERCOM and the complementary between TERCOM and K-mean algorithm, a new method based on the integration of TERCOM and K-means clustering algorithm is studied and presented in this paper so as to get ideal matching accuracy and reliability. The integrated method will be depicted in detail in this paper.

II. PRINCIPLE OF TERCOM

The geomagnetic total intensity changes with position. Different positions have different geomagnetic value. In order to obtain the geomagnetic total intensity by location, we use the background field model which can be used for establishing the digital geomagnetic database. The geomagnetic data and the corresponding geographical coordinates are saved in the database. Then, we use the real-time observation sequence of geomagnetic total intensity and the corresponding data stored in the geomagnetic database to implement matching analysis. TERCOM algorithm is used for playing the role [1].

TERCOM work's basis is correlative analysis. There are three algorithms to be used for correlative analysis, which are the cross-correlation (COR) algorithm, the average absolute difference (MAD) algorithm and the standard deviation (MSD) algorithm respectively, which are depicted in detail as following [2].

$$COR(\tau_x,\tau_y)=\frac{1}{L}\int_{-l/2}^{l/2}T_A(x,y)*T_s(x+\tau_x,y+\tau_y)dl \tag{1}$$

$$MAD(\tau_x,\tau_y)=\frac{1}{L}\int_{-l/2}^{l/2}\left|T_A(x,y)-T_s(x+\tau_x,y+\tau_y)\right|dl \tag{2}$$

$$MSD(\tau_x,\tau_y)=\frac{1}{L}\int_{-l/2}^{l/2}\left[T_A(x,y)-T_s(x+\tau_x,y+\tau_y)\right]^2 dl \tag{3}$$

Where, τ_x is the offset value in the direction to be parallel to x-axis, while τ_y is the offset value in the direction to be parallel to y-axis. T_A is the geomagnetic total intensity measured by the magnetometer, while T_S is that stored in the geomagnetic database at the position ($x+\tau_x$, $y+\tau_y$). L is the matching length.

In above correlative analysis algorithms, when COR becomes maximum, while both MAD and MSD become minimum, we think that the real-time observation sequence of geomagnetic total intensity fulfills the best matching with the geomagnetic background field (namely geomagnetic database) at this time. The position of the real-time observation sequence is also that of the underwater vehicle, which will be used for adjusting the estimated position and orientation from inertial navigation system (INS).

Funded the HI-TECH RESEARCH AND DEVELOPEMNT PROGRAM OF CHINA (863 Program) with authorized number of (2007AA12Z326) and (2009AA12Z311)

TABLE I
THE POSITIONING ERROR BY TERCOM IN DIFFERENT GEOMAGNETIC DISTRIBUTION AREAS AND NOISE SITUATIONS

Noise / Error/m	Similar area				Complex area			
	0 /nT	4 /nT	6 /nT	10 /nT	0 /nT	4 /nT	6 /nT	10 /nT
1	101	295	654	998	65	65	494	694
2	119	315	585	936	115	115	514	714
3	155	354	532	1067	140	140	554	754
4	191	387	667	1010	32	32	586	786
5	48	247	620	949	53	53	446	646
6	89	288	547	934	125	125	488	688
7	139	327	518	959	169	169	520	723
8	186	378	536	996	181	181	572	775
9	125	321	638	968	58	58	520	719

In order to test the TERCOM performance, we implement two experiments in different geomagnetic distribution areas and noise situations. The positioning errors are shown in TABLE I. After the experiments in different geomagnetic distribution areas and noise situations, two performances of this algorithm are found. One is matching accuracy which will become worse when noise exits in geomagnetic observation data. The other is stability. This algorithm has poor stability in the similar geomagnetic distribution area.

III. PRINCIPLE OF K-MEAN ALGORITHM

In order to improve above shortcomings of TERCOM, K-mean algorithm is introduced in the match positioning.

K-mean algorithm can divide the whole data into K clusters. The data in the same cluster has the higher similarity. Based on above characteristic, K-mean algorithm is used for dividing the whole MSD into K clusters. K-means algorithm requires that the square of the distance from various samples to the cluster center is minimum, which is based on the criteria that the sum of the error square is least [3]. The algorithm is implemented by follows steps.

(1) Firstly, K initial clustering centers, such as $z_1(1)$, $z_2(1)$, $z_3(1)$, …, $z_k(1)$, are selected randomly. Generally they are the former K clustering centers of these samples.

(2) According to the principle of the minimum distance to the initial clustering centers, every MSD is assigned to K clustering centers. The m-time iterations are expressed by (4).

$$\left\|x-z_j(m)\right\|<\left\|x-z_i(m)\right\|, i=1,2,3\ldots k, i\neq j \qquad (4)$$

(3) By step (2), we can get the new clustering centers, they are the $Z_i(m)$ (i=1,2,3…K) expressed as (5)

$$z_i(m+1)<\frac{1}{N_i}\sum_{x\in f_i(m)}x, i=1,2,3\ldots.K \qquad (5)$$

In (5), N_i is the number of samples at i^{th} cluster $f_i(m)$. The mean vectors are thought to be the new clustering centers. Above processing can make the sum of error square J reach minimum.

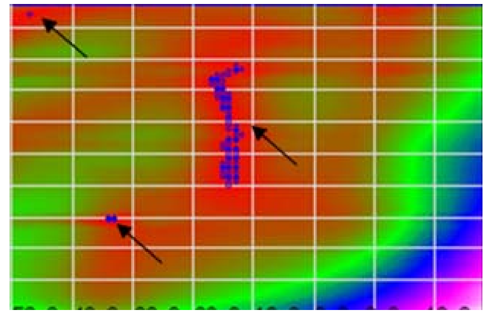

Fig1, The figure of the clustered MSD by K-Mean

$$J=\sum_{i=1}^{k}\sum_{x\in f_i(m)}\left\|x-z_i(m+1)\right\|^2, i=1,2,3\ldots.K \qquad (6)$$

(4) If $z_i(m+1)$ equals $z_i(m)$, then the K-mean algorithm is finished. Otherwise return to steps (2) and let $m = m + 1$, for the next iteration.

Based on above characteristic, K-mean algorithm is used for dividing the whole MSD into K clusters. Through choosing the appropriate threshold, the cluster, which MSD is close to the minimum MSD, can be found. As we know, the more accurate observation data we have, the higher stability the matching navigation will get. Therefore, all of MSDs in the cluster processing can be used to judge the right matching area, especially in the match positioning with the polluted geomagnetic observation data as well as the match positioning in the similar geomagnetic distribution area.

In Fig. 1, using the K-mean algorithm, the cluster, which's MSD is close to the minimum MSD, can be found. In this experiment, we can get three areas which have the similar MSD with the right area (As shown by the arrow in Fig. 1). If we only use TERCOM, we can not get any other two results which may contain the right result. By the experiment, the advantage and the disadvantage of the K-means algorithm is found. The algorithm can get more similar MSD with the minimum MSD, which can be used for judging the right matching area. Especially in the similar geomagnetic area, it can get more useful navigation information. However, the red areas in Fig. 1, which have the similar MSD with the minimum MSD, are large, but only one right MSD exists in the area. Therefore, it is difficult to judge the right one in the similar MSD by the K-means algorithm. In other words, although the algorithm gives out the probability of actual location, but where the location is needs to be answered.

IV. THE NEW ALGORITHM OF THE INTEGRATION OF TERCOM, K-MEANS CLUSTERING AND INS

By above researches, it is not difficult to find that the two algorithms have strong complementary each other. In order to use the advantage of them, in this section, a new matching navigation method, the integration of TERCOM, K-mean clustering algorithm and INS (inertial navigation system) are studied.

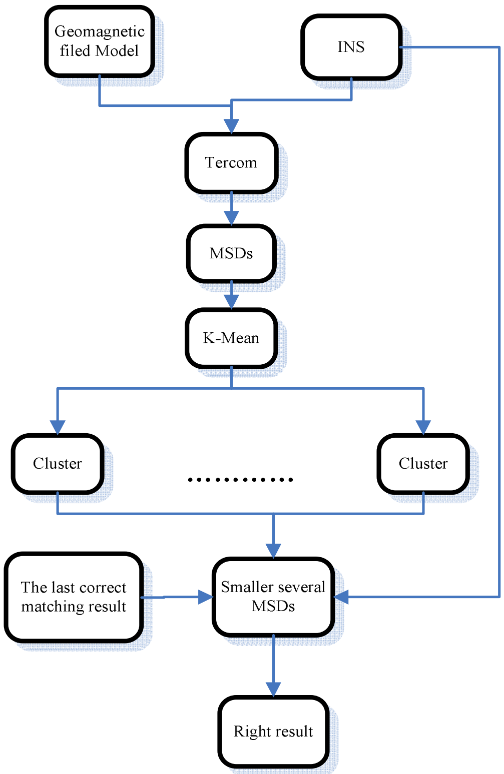

Fig2. The Flowchart of the Algorithm

A completed matching procedure of the integrated matching navigation method is given out and depicted as following. The flowchart is shown as Fig. 2.

Firstly, the TERCOM algorithm is still used as main navigation. Through a series of iterative process, all of MSD in different steps are got and the minimum MSD is found.

Then, through choosing the appropriate K value and the truncation threshold, K-mean algorithm is used for clustering the MSD which are the similar to the minimum MSD

In these locations corresponding to these clustered MSDs, the optimum matching result can be found from them. The smaller several MSD may be acquired in the similar areas, and is clustered in a class by K-mean algorithm. If we can not correctly judge the true one, the mismatching may be produced. In order to eliminating the uncertainty, by means of the last correct matching result and the current matching results, the orientations and distances between them can be calculated. Comparing them with that from INS, an optimum current matching result, which is well consistent with the INS result, is found. The position corresponding to the optimum current matching result is also the actual position of underwater vessel

V. Experiment and Performance Analysis of the Integration Algorithm

Based on the above research, an experiment is implemented for evaluating the accuracy and the stability of this new method. Experimental result and some conclusions are depicted as follows.

We implemented a geomagnetic measurement in a 10 km × 10 km water area. The interval of surveying lines was set as 100 meters and the interval of measuring points was set as 15 meters in the actual geomagnetic measurement. These geomagnetic data are used for the geomagnetic background field modeling. After data processing, the accuracy of the background geomagnetic field model in this area reaches 2.37 nT [4][5].

In implementing the experiment, both INS and D-GPS were set on the surveying vessel. In order to verify the accuracy of this new method, the positioning result from D-GPS is used for comparing with the result of the matching navigation. The parameters of INS and the track length are listed in TABLE II.

MSD algorithm is used as the diagnostic standard of correlative analysis in TERCOM. The 2-time standard deviation is used as the truncation threshold in the K-mean algorithm.

After the matching navigation by the new method, the error distribution of the new method is shown in Fig. 3.

According to Fig. 3, the new method can get better matching position than TERCOM method. The mean square errors of points by the new method are from 0 to 50m, which is obviously better than the traditional method. The mismatching in the new method is also eliminated effectively.

Both the track figure and the MSD figure are shown in Fig. 4. From the figure, we can find that the MSD corresponding to the mismatching track is similar with the MSD of the true track. The tradition method can not separate them well, while the integrated method can do well.

TABLE II
The Parameters in the Experiment

Parameter	Value
Initial *x* location error /m Initial *y* location error /m	3500 3500
Initial INS angle error /°	1
Gyro zero-bias (°/h)	0.0001
Grid width /m	50
Grid accuracy /nT	2.89
Track length/km	3
Truncation threshold	2

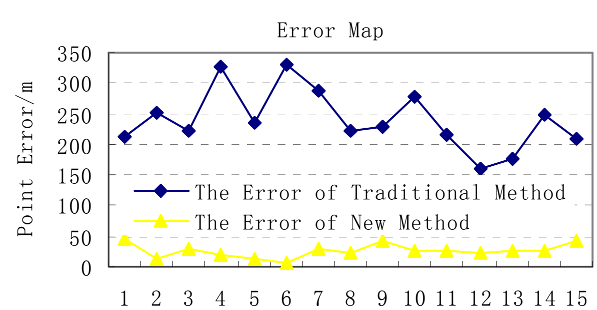

Fig3. The error map of the new method

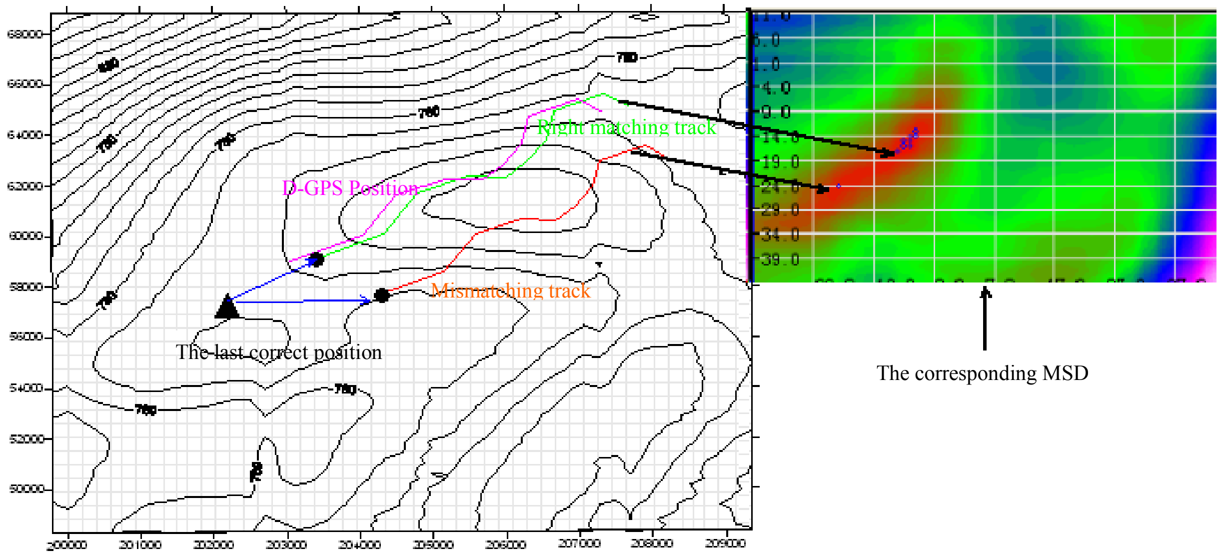

Fig.4 The chart of the background, vessel track and the corresponding MSD

VI. CONCLUSIONS

By above research, some very useful conclusions are given out as following

(1) By means of traditional TERCOM matching navigation, the matching accuracy will become worse when noise exits in geomagnetic observation data. This algorithm also has poor stability in the similar geomagnetic distribution area.

(2) The new method, which is based on integration of TERCOM, K-means clustering algorithm and INS, can get more accuracy and stability navigation results than the traditional method. The mismatching is also eliminated effectively by the new method.

ACKNOWLEDGMENT

The research has been sponsored by HI-TECH RESEARCH AND DEVELOPEMNT PROGRAM OF CHINA (863 Program) with authorized number of 2007AA12Z326 and 2009AA12Z311. We also wish to thank the Ocean 2010 committee for providing this chance to present our research, and the IEEE for providing technical support in the presentation.

REFERENCES

[1] Zhao jianhu, Wang shengping Wang Aixue.An Improved TERCOM Algorithm for Underwater Geomagnetic Matching Navigation. Geomatics and Information Science of Wuhan University. Vol.34 No.11 Nov. 2009.p1320-p1323

[2] Jianhu Zhao, Shengping Wang and Aixue Wang, .Study on Underwater Navigation System Based on Geomagnetic Match Technique. The international conference on Electronic Measurement & Instruments(ICEMI 2009) Aug 2009. Beijing., China..

[3] Ning Shu, Hongchao Ma Lihe Sun, The theories and Methods of Pattern Recogntion Wuhan university Press. Dec 2004.

[4] Shengping Wang, Jianhua Zhao, Hongmei Zhang. Study on key technologies of Construction of Marine Geomagnetic Filed Model Based on Polynomial Method. Ocean'08 MTS/IEEE, Quebec, Ocean & Polar Climate: Technology Challenged, Sept.15-18,2008. Quebec City Convention Center, Quebec City, Canada

[5] Jianhu Zhao, Hui Liu and Shengping Wang. Study on Building Local Marine Geomagnetic Field Model Based on Interpolation Method, Ocean'08 MTS/IEEE, Quebec, Ocean & Polar Climate: Technology Challenged, Sept.15-18,2008. Quebec City Convention Center, Quebec City, Canada,