# Geomagnetic Matching Combined Navigation Based on Improving Operation Efficiency of DTW Algorithm

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***Abstract*—Aiming at the problem of "singularity" generated by the traditional DTW matching algorithm, the DDTW matching algorithm is used to match the geomagnetic sequence, and the first derivative of the sequence is compared for matching, and the Itakura window is used as a constraint to restrict the search range. In order to improve the overall positioning effect, a combination of inertial navigation and geomagnetism is used for navigation, and Kalman filtering is used to fuse the positioning results. Experimental results show that when the matching window is 60, the average positioning error of the system using the improved DDTW matching algorithm is within 1.37m. Compared with the system using the DTW matching algorithm, the average positioning error is reduced by 0.59m and effectively improved Computing efficiency.**

***Keywords—ntegrated navigation, derivative dynamic time warping, Itakura window, derivative dynamic time warping, Kalman filtering***

## I. INTRODUCTION

Inertial Navigation System,it is an autonomous navigation system that does not need to provide external information and does not radiate energy to the outside [1],and has important strategic significance.However, INS will produce navigation errors, which will accumulate over time, and long-term use will result in poor positioning accuracy.Therefore, the commonly used method is to use it as an auxiliary navigation in other navigation systems[2]. Geomagnetic matching navigation has the advantages of all-time, all-region, low-cost, low-power, passive, and non-radiation, and has applications in many fields[3].The geomagnetic/INS integrated navigation positioning method can combine the positioning advantages of the two methods, and use the characteristic of geomagnetic matching that the cumulative error does not change over time to correct the INS positioning error[4].Scholars at home and abroad have started research on geomagnetic/INS integrated navigation and positioning technology. Many domestic institutions such as the Third Academy of Aeronautics and Astronautics, Beijing University of Aeronautics and Astronautics have conducted INS/geomagnetic integrated navigation research[5],Florida Atlantic University in the United States[6],the British Sears Institute[7] also carried out research on INS and geomagnetic matching navigation technology [8].

The algorithm often used in geomagnetic matching navigation and positioning is the dynamic time warping (Dynamic Time Warping, DTW) matching algorithm, but there is a "singularity" problem in the traditional DTW algorithm.In this paper,the Derivative Dynamic Time Warping (DDTW) matching algorithm is used to match the geomagnetic sequence.In order to reduce the amount of calculation, this paper uses Itakura window as a constraint condition to restrict the search range.At the same time, INS is used to assist geomagnetic matching navigation and positioning, and the Kalman filter method is used to combine the positioning results of the two.In the positioning algorithm proposed in this paper,DDTW effectively alleviates the "singularity" problem, and the addition of the Itakura parallelogram window reduces the computational complexity of the algorithm.

## II. GEOMAGNETIC MATCHING ALGORITHM

### A. DTW matching algorithm

The DTW matching algorithm is a way to measure the similarity of two time series with different lengths,and is used for information retrieval,data mining,and so on.The core content of the DTW matching algorithm is based on the idea of dynamic programming (DP).This method achieves more accurate matching of sequence templates with different lengths [9].Assuming two different time series

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$Q(q_1, q_2, ..., q_i, ..., q_n)$ and $C(c_1, c_2, ..., c_j, ..., c_m)$ ,let $D(n \times m, n \neq m)$ and $D$ be the cumulative distance matrix. The element $d(i,j) = (q_i - c_j)^2$ in $D$ represents the Euclidean distance between the point $q_i$ in $Q$ and the point $c_j$ in $C$ . The idea of dynamic programming in $D$ is to find an optimal path with the smallest cumulative distance among all possible paths from the starting point $d(1,1)$ to $d(n,m)$, and the distance of the path $L$ is the dynamic regularized distance. The DTW matching algorithm rules the path to follow three principles:

- Boundary: The initial point must be (1,1) ,and $\max(m,n) \le d_L \le m+n$ and $d_L$ are the length of the path $L$.
- Continuity: The elements in path $L$ are continuous.
- Monotonicity: The previous step of $L$ passing through $(i,j)$ can only be one of $(i-1,j)$, $(i,j-1)$, $(i-1,j-1)$ and the point $(i,j)$ is to select the point corresponding to the smallest distance among the above three points as the previous point, and further obtain the cumulative distance $D(i,j)$. The specific method is as follows:

$$D(i,j) = d(i,j) + \min \begin{cases} D(i-1,j) \\ D(i,j-1) \\ D(i-1,j-1) \end{cases} \quad (1)$$

In the formula, $D(i,j)$ is the cumulative matching distance, and $d(i,j)$ is the distance between two geomagnetic sequences.

### B. DDTW matching algorithm

The realization of the DTW matching algorithm is to interpret the Y-axis variables by "distorting" the X-axis, so that two different time series can be matched and aligned. But this will also bring "unintuitive" alignment. As shown in Figure 1, it will cause a point in a sequence to map to another sequence. It is not a single point, but there may be multiple uncertain points. This problem is called The "singularity" problem.

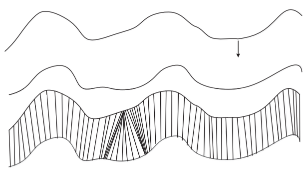

Fig. 1.Schematic diagram of the singularity problem of DTW algorithm

In response to this problem, the slope of the sequence is used for comparison, and the sequence is matched according to the changing trend of the sequence. The first derivative in mathematics reflects the slope, so we can use this feature to obtain the changing trend of the sequence. We call this method the DDTW matching algorithm. The comparison of the sequence size in the DTW matching algorithm is to calculate the Euclidean distance between the two sequences, and then select the path with the shortest cumulative distance as the final path. The DDTW matching algorithm compares the square of the derivative difference between every two points, which is different from the DTW matching algorithm. The complexity of the DDTW matching algorithm is $o(mn)$, and the calculation formulas are shown in equations (2) and (3).

$$r(i,j) = (R(p_i) - R(q_j))^2 \quad (2)$$

$$R_x[p] = \frac{(p_i - p_{i-1}) + ((p_{i+1} - p_{i-1})/2)}{2} \quad 1<i<m \quad (3)$$

In the above formula, $r(i,j)$ represents the corresponding slope value $R(p_i)$ of point $p_i$ and point $q_j$ minus the square of the result of the slope value $R(q_j)$. $p_i - p_{i-1}$ represents the slope value between point $i$ and a point before point $i$, $(p_{i+1} - p_{i-1})/2$ represents the slope value between a point before point and a point after point , $R_x[p]$ is the average of $(p_i - p_{i-1})$ and $(p_{i+1} - p_{i-1})/2$ .Compared with using the distance between two data points for comparison, trend matching is more robust. Use the DDTW matching algorithm to calculate directly from the second point and the penultimate point when calculating equations (2) and (3), excluding the first point and the end point, where $R(q_0) = R(q_1)$, $R(q_m) = R(q_{m-1})$ .In the DTW method, the cumulative distance matrix $D(i,j)$ is used to represent and save, in the DDTW, the similarity matrix $L(p,q)$ is used to represent. The calculation method of $L(p,q)$ is shown in formula (4).

$$L(p,q) = r(i,j) + \min \begin{cases} L(i-1,j) \\ L(i,j-1) \\ L(i-1,j-1) \end{cases} \quad (4)$$

In the formula, $L(p,q)$ represents the cumulative similarity, and $r(i,j)$ represents the sum of the squares of the derivative differences between the two sequences.

### C. DDTW matching algorithm based on global constraints

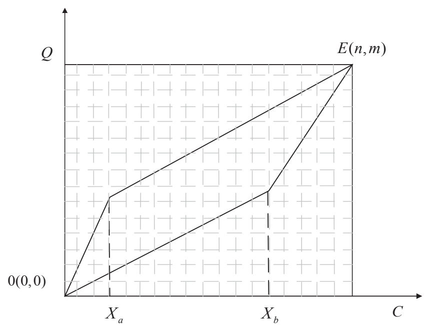


Fig.2. Schematic diagram of matching path constraints

The scholar Itakura [10] proposed a solution for the higher complexity of the DTW algorithm. A parallelogram window was added in the regularization process. During the sequence matching process, the path to calculate the square

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of the slope difference between the two sequences is reduced. The amount of calculation for each calculation is also reduced, so the overall computational complexity of the algorithm is also reduced. Figure 2 is a schematic diagram of matching path constraints.

In Figure 2, usually the slope of one side of this constraint window is set to 1/2, then the slope of the corresponding other side is set to 2, and the regular route starts from $(1,1)$ and ends at $(n,m)$ . $X_a$ and $X_b$ represent two different intersections of the two sides with slopes of 1/2 and 2, $\boldsymbol{C}$ and $\boldsymbol{Q}$ represent the sequence to be matched, and $E(n,m)$ represents the end point of the path regularization. When $X_a < X_b$, the matching path is divided into 3 segments, $(1,X_a)$ , $(X_{a+1},X_b)$ and $(X_{b+1},n)$, the relationship between , $X_a$ 、 $X_b$ 、 $m$ 、 $n$ is as follows ( 5) Shown:

$$\begin{cases} X_a = \dfrac{1}{3}(2m - n) \\ X_b = \dfrac{2}{3}(2n - m) \end{cases} \tag{5}$$

Because $X_a$ and $X_b$ are not decimals, it will choose the value to the shortest integer value between $X_a$ and $X_b$, so the length of $m$ , $n$ must satisfy the condition of formula (6):

$$\begin{cases} 2m - n \geq 3 \\ 2n - m \geq 2 \end{cases} \tag{6}$$

If the above conditions are not met, that is, there is too much difference between the two sequences, and the dynamic matching can not be performed.

The difference with DTW is that DTW has to calculate the distance between each point in two different sequences. At this time, the abscissa and the grid point between $(y_{\min}, y_{\max})$ can be calculated, which is the same as the ordinate outside the constraint window. No calculations are required. The value range of $(y_{\min}, y_{\max})$ is as follows:

$$y_{\min} = \begin{cases} \dfrac{1}{2}x, 0 \leq x \leq X_b \\ 2x + (m - 2n), X_b < x \leq n \end{cases} \tag{7}$$

$$y_{\max} = \begin{cases} 2x, 0 \leq x \leq X_a \\ \dfrac{1}{2}x + (m - 2n), X_a < x \leq n \end{cases} \tag{8}$$

There is another case where $X_a > X_b$ , $(1,X_a)$ , $(X_{a+1},X_b)$ and $(X_{b+1},n)$ in the previous case are converted to $(1,X_b)$ , $(X_{b+1},X_a)$ , $(X_{a+1},n)$ .

In the dynamic programming process after the constraint window is added, the length on the Y-axis that needs to be compared by sliding one step forward on the X axis is different from that before the constraint window, but the characteristics are the same. The cumulative matching similarity is:

$$\boldsymbol{L}(i,j) = r(i,j) + \min \begin{cases} \boldsymbol{L}(i-1,j) \\ \boldsymbol{L}(i\text{-}1,j-1) \\ \boldsymbol{L}(i-1,j-2) \end{cases} \tag{9}$$

For each sliding step on the X-axis, the cumulative similarity matrix of the previous column is used. The accumulated similarity matrix of the previous column is represented by matrix $\boldsymbol{L}$ and used for the next matching, and the accumulated similarity matrix of the calculated column is represented by $\boldsymbol{r}$ and used for the next matching. This is different from the traditional algorithm which needs to keep all the similarity matrices. The matrix is updated every sliding step. This feature can save storage space. Whenever you slide one step, update it according to equation (9), use the cumulative similarity $\boldsymbol{L}$ of the previous column and the similarity matrix $r(i,j)$ of the current column to find the cumulative similarity matrix of the current column, save it in the vector $\boldsymbol{r}$, and save this The result of the updated $\boldsymbol{r}$ is converted to $\boldsymbol{L}$, replacing the previous $\boldsymbol{r}$ into a new cumulative similarity matrix, ready for the next column call. This starts from the first column until the last column of the X axis.

## III. INS/Geomagnetic Matching Integrated Navigation

### A. *Principles of integrated navigation positioning*

The realization of outdoor geomagnetic matching integrated navigation is mainly divided into two parts. The first part is to establish a discrete geomagnetic database, using GPS482 combined with a magnetometer to establish a discrete geomagnetic database. The second part is the online matching process. The improved DTW matching algorithm is used to match the geomagnetic sequence collected online with the data sequence of the offline database in real time. The parameters such as speed error, attitude error and gyroscope drift provided by the INS are taken as its status. The difference between the position information calculated by the INS positioning and the position calculated by the geomagnetic navigation positioning is used as the observation measurement, and the error of the inertial navigation is estimated through the Kalman filter [11], and the error of the inertial navigation is adjusted, so as to obtain The final result. The specific process is shown in Figure 3.

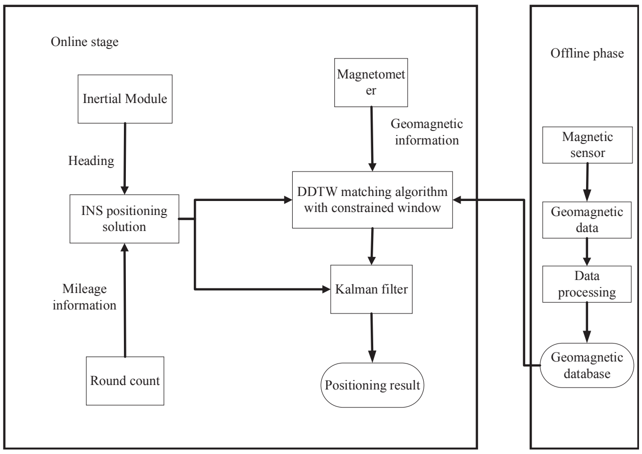


Fig.3. Flow chart of geomagnetic/INS integrated navigation system based on constrained window DDTW algorithm


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### B. Experimental process of INS/geomagnetic integrated navigation

In this experiment, first collect the geomagnetic data. The JY901 is used to measure the geomagnetic data, and the frequency of JY901 is 20Hz. First, the inertial device is used to output the measurement result of the positioning area that needs to be measured, and then a series of geomagnetic field values corresponding to the output position are output. The output geomagnetic field value and the geomagnetic sequence measured by the magnetic sensor are correlated and matched. The geomagnetic matching method adopts the improved DTW matching algorithm to obtain the best matching position with the output geomagnetic field value, and then match it out The position and the position output by the inertial navigation system are output as the input value and input into the filtering method, and the positioning information of the two is filtered and fused. The experiment was carried out outdoors, and the matching window sizes corresponding to the experiment were 20, 40, and 60 respectively.

The experiment is based on the DTW matching algorithm and the improved DTW matching algorithm to solve the test trajectory. The experimental parameters are shown in Table 1:

TABLE I. EXPERIMENTAL PARAMETERS

| *parameter* | *Parameter value* |
|---|---|
| *Initial position/(°)* | ***latitude*** 31.325 25<br>***longitude*** 120.427 8 |
| *Initial speed/m·s-1* | 1 |
| *Initial horizontal attitude/(°)* | 0 |
| *Gyro constant drift* | 0.03 |
| *(Equal three axes)/ (°)·h-1* | 0.005 |
| *Gyro random drift* | 0.001$g$ |
| *(Equal three axes)/ (°)/ ·h-1* | 0.000 5$g$ |
| *Accelerometer stable offset* | 1.407 6 |
| *(The three axes are equal)* | 20 |
| *Random offset of accelerometer* | $0.000\,001^{o} \times 0.000\,001^{o}$ |
| *(The three axes are equal)* | 0.1 |
| *Measure the noise standard deviation of magnetic anomalies/dB* | 0.1 |
| *Online sampling magnetoresistive sensor sampling frequency/Hz* | 1 |
| *The accuracy of the geomagnetic reference map in the test area* | 1 |
| *The starting position of the cruiser* | 0.000 1 |
| *East speed error/m·s-1* | 0.000 05 |

## IV. ANALYSIS OF EXPERIMENTAL RESULTS

### A. Positioning results

In this experiment, the geomagnetic data matching and positioning results are shown in Figure 4 by using the DTW matching algorithm, the DDTW matching algorithm and the constrained DDTW matching algorithm proposed in this chapter. Figure 5 shows the corresponding longitude and latitude trajectories.

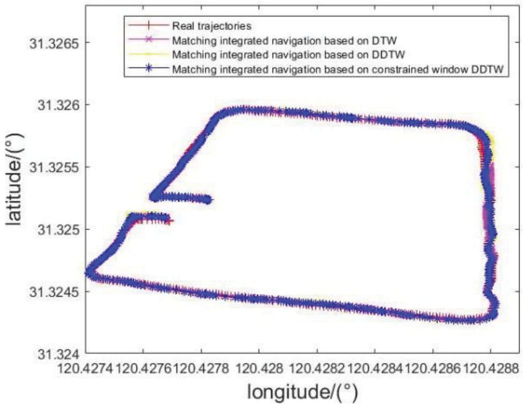


Fig.4. Positioning track comparison

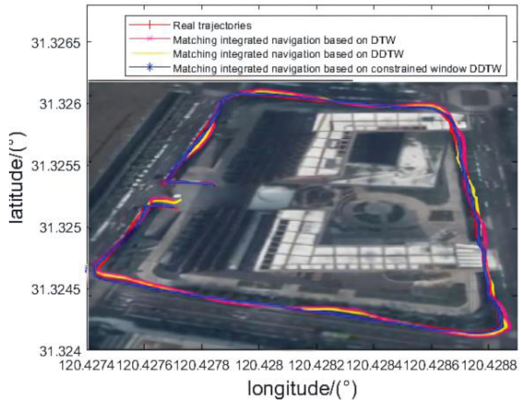


Fig.5. Google Maps Location Track

### B. Running time analysis

In order to study the computing time of the three matching algorithms, in this experiment, the average value of 100 consecutive positioning times at a test point is used to represent the time used for one positioning, and the matching window sizes are 20, 40, and 60, respectively. The experimental results are shown in Table 2.

TABLE II. THREE KINDS OF MATCHING ALGORITHMS COMBINED NAVIGATION SINGLE POSITIONING TIME

| *Match window size* | *Average positioning time* | | |
|---|---|---|---|
| | *DTW/s* | *DDTW/s* | *DDTW/s with bound window* |
| 20 | 2.05 | 2.07 | 1.89 |
| 40 | 3.14 | 3.12 | 2.06 |
| 60 | 3.89 | 4.01 | 2.12 |

From Table 2, under different matching windows, the running time of DTW matching algorithm and DDTW matching algorithm is very close. From the first two chapters, we know that the complexity of DTW matching algorithm and DDTW matching algorithm are both, so the operational efficiency of the two algorithms is similar. The calculation time of the DDTW matching algorithm with a constraint window under different matching windows is shorter than that of the DDTW matching algorithm without a constraint window, and the difference in running time becomes more obvious with the increase of the matching window. This is because of the matching window. The more data sequences, and the more calculations that reduce the constraint window, the more the complexity of the algorithm is reduced. When


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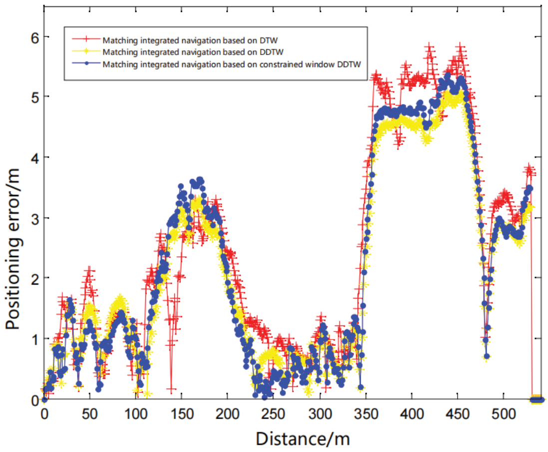
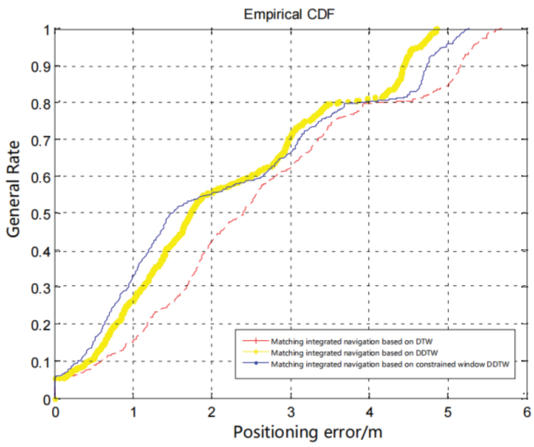
the matching window is 20, 40, 60, the running time of the DDTW matching algorithm with constraint window is reduced by 7.81%, 34.39%, and 45.50% respectively than that of the DTW matching algorithm. Effectively reduce the running time of the algorithm.

### *C. Analysis of positioning accuracy*

This section compares and analyzes the positioning accuracy of the three algorithms in the experimental area. The sliding matching windows are respectively 20, 40 and 60, and different positioning error comparison maps and cumulative error distribution maps corresponding to different sliding matching windows are obtained. As shown in Figure 6, Figure 7 and Figure 8, respectively. The detailed pairs of positioning errors corresponding to different sliding matching windows are shown in Table 3, Table 4, and Table 5, respectively.




(a) Positioning error comparison chart




(b) Cumulative error probability distribution chart

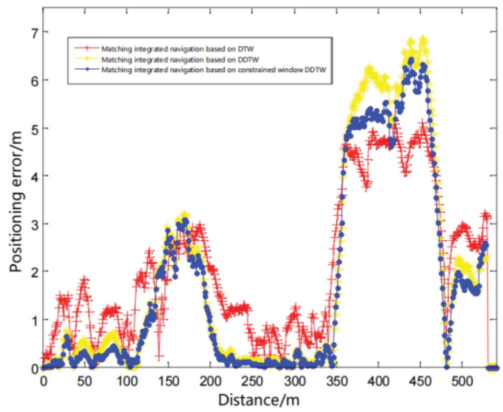
Fig.6. Experimental data with a matching window of 20

It can be seen from Figure 6 and Table 3 that when the matching window is 20, the positioning accuracy of this positioning system using the DTW matching algorithm has a 15.74% probability of 0~1m, and the average accuracy is 2.61m. The positioning accuracy using the DDTW matching algorithm has a 26.75% probability of 0~1m, and the average accuracy is 2.28 meters. The positioning accuracy of the DDTW matching algorithm with constrained window has a 33.89% probability of 0~1m, and the average accuracy is 2.26m.

TABLE III. COMPARISON OF POSITIONING ERROR WHEN THE MATCHING WINDOW IS 20

| ***Targeting method category*** | ***Positioning error range/m*** | | | | ***Average accurac y/m*** |
|---|---|---|---|---|---|
| | ***0~1*** | ***0~2*** | ***0~3*** | ***0~4*** | |
| ***Matching integrated navigation based on DTW*** | 15.74 % | 42.58 % | 61.79 % | 77.89 % | 2.61 |
| ***Matching integrated navigation based on DDTW*** | 26.75 % | 55.42 % | 70.89 % | 80.25 % | 2.28 |
| ***Matching integrated navigation based on constrained window DDTW*** | 33.89 % | 55.41 % | 66.97 % | 80.35 % | 2.26 |

It can be seen from Figure 7 and Table 4 that when the matching window is 40, the positioning accuracy using the DTW matching algorithm in the positioning system has a 21.11% probability of 0~1m, and the average accuracy is 2.27m. The positioning accuracy using the DDTW matching algorithm has a 56.71% probability of 0~1m, and the average accuracy is 2.01 meters. The positioning accuracy of the DDTW matching algorithm with constrained window has a 57.09% probability of 0~1m, and the average accuracy is 1.79m.




(a) Positioning error comparison chart


（b）Cumulative error probability distribution chart

Fig.7. Experimental data with a matching window of 40


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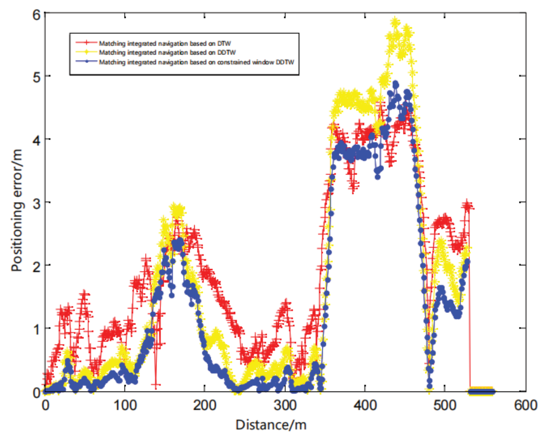
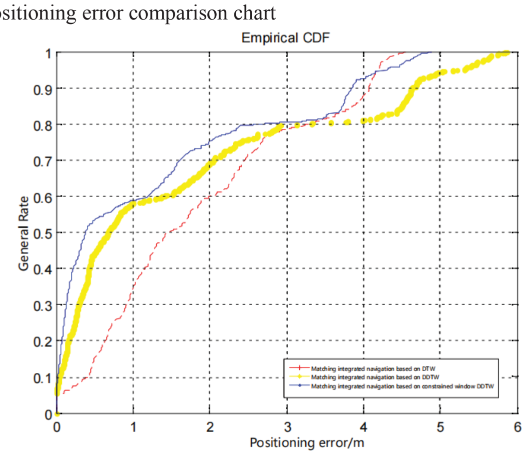
TABLE IV. COMPARISON OF POSITIONING ERRORWHEN THE MATCHING WINDOW IS 40

| *Targeting method category* | *Positioning error range/m* | | | | *Average accuracy/m* |
|---|---|---|---|---|---|
| | *0~1* | *0~2* | *0~3* | *0~4* | |
| ***Matching integrated navigation based on DTW*** | 21.11 % | 54.38 % | 74.61 % | 80.43 % | 2.27 |
| ***Matching integrated navigation based on DDTW*** | 56.71 % | 68.38 % | 76.45 % | 80.48 % | 2.01 |
| ***Matching integrated navigation based on constrained window DDTW*** | 57.09 % | 69.47 % | 79.15 % | 81.35 % | 1.79 |

It can be seen from Figure 8 and Table 5 that when the matching window is 60, the positioning accuracy of this positioning system using the DTW matching algorithm has a 34.06% probability of 0~1m, and the average accuracy is 2.27m. The positioning accuracy using the DDTW matching algorithm has a 55.45% probability of 0~1m, and the average accuracy is 2.01 meters. The positioning accuracy of the DDTW matching algorithm with constrained window has a 57.69% probability of 0~1m, and the average accuracy is 1.79m.




(a) Positioning error comparison chart




(b) Cumulative error probability distribution chart

Fig.8. Experimental data with a matching window of 60

TABLE V. COMPARISON OF POSITIONING ERRORWHEN THE MATCHING WINDOW IS 60

| *Targeting method category* | *Positioning error range/m* | | | | *Average accuracy/m* |
|---|---|---|---|---|---|
| | *0~1* | *0~2* | *0~3* | *0~4* | |
| ***Matching integrated navigation based on DTW*** | 34.06 % | 59.85 % | 76.34 % | 85.29 % | 1.96 |
| ***Matching integrated navigation based on DDTW*** | 55.45 % | 66.79 % | 78.28 % | 81.15 % | 1.72 |
| ***Matching integrated navigation based on constrained window DDTW*** | 57.69 % | 74.51 % | 80.43 % | 92.28 % | 1.37 |

Combining Table 3, Table 4, and Table 5, a comparison table of the positioning average accuracy of the three matching algorithms is sorted out, as shown in Table 6.

TABLE VI. COMPARISON OF THE AVERAGE ACCURACY OF THREE MATCHING ALGORITHMS COMBINED NAVIGATIO

| *Match window size* | *Average positioning accuracy* | | | *Match window size* |
|---|---|---|---|---|
| | *DTW/m* | *DDTW/m* | *DDTW with constrained window/m* | |
| 20 | 2.61 | 2.28 | 2.26 | 20 |
| 40 | 2.27 | 2.01 | 1.79 | 40 |
| 60 | 1.96 | 1.72 | 1.37 | 60 |

It can be concluded from Table 6 that the average positioning accuracy of the system using the DDTW matching algorithm is higher than that of the system using the DTW matching algorithm. This shows that the DDTW matching algorithm uses the first derivative difference method than the DTW matching algorithm using Euclidean distance. The method is more accurate. And as the matching window increases, the DDTW matching algorithm with constraint window has a higher positioning accuracy than the DTW matching algorithm. This is because as the matching window increases, the possibility of ill-formedness with reduced constraint conditions increases. When the matching window is 60, the positioning accuracy of the DDTW matching algorithm with the constraint window reaches 1.37m, which is 0.59m higher than the positioning accuracy of the DTW matching algorithm. In addition, as the matching window increases, the probability of the positioning errors of the three matching algorithms within 1m and 2m increases. This is because the larger the matching window, the longer the geomagnetic data sequence in the matching window, and the greater the trend of change. With uniqueness, the higher the positioning accuracy. However, if the data is too long, the change characteristics of the data sequence in a short period of time are not obvious. Therefore, the matching window is generally set between 1/30 and 1/10 of the total length of the data sequence, so the matching window is selected in the larger value of the optional area. Will get a higher accuracy.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## V. CONCLUSION

Aiming at the "singularity" problem generated in the DTW matching algorithm, this paper adopts an improved DDTW matching algorithm, which matches the first derivative of the sequence, and uses the Itakura window as a constraint to restrict the search range. It not only improves the efficiency of the algorithm, but also improves the positioning accuracy. However, due to the limitations of space and equipment, the experimental environment is relatively simple, and the subsequent improvements will continue to improve the algorithm to quickly and accurately locate the target in a more complex environment.

## REFERENCES


[1] Fengyang Li, Xuedong Jia, Ming Dong. Development of inertial/visual integrated navigation in different application scenarios[J]. Journal of Navigation and Positioning, 2016, 4(04): 30-35.

[2] Yang Chunlei. Research on UAV strapdown inertial/all-optical autonomous integrated navigation system[J]. Journal of Sichuan Armed Forces, 2015, 36(11): 4-7.

[3] Sun Meng, Wang Yunjia, Zhou Jiapeng, Xu Shenglei, Si Minghao. A geomagnetic positioning algorithm based on fast dynamic time warping [J/OL]. Science of Surveying and Mapping: 1-7.

[4] Duan Benyin. Geomagnetic assisted inertial integrated navigation system technology research [D]. Harbin Institute of Technology, 2012.

[5] Wu Meiping, Liu Ying, Hu Xiaoping. Application of ICP Algorithm in Geomagnetic Aided Navigation[J]. Aerospace Control, 2007(06): 17-21+26.

[6] Grenon G , An E , Smith S . Enhancement of the inertial navigation system of the Florida Atlantic University autonomous underwater vehicles[C]// International Symposium on Underwater Technology. IEEE, 2000.

[7] Smith R , Frost A , Probert P . Aspects of heading determination via fusion of inclinometer and magnetometer data[C]// Advanced Robotics, 1997. ICAR '97. Proceedings. 8th International Conference on. 1997.

[8] Ding Baichao. Intelligent segmentation fusion method for inertial/geomagnetic integrated navigation[J]. Journal of Navigation and Positioning, v.5; No.20(04):1-5.

[9] Yao Zhao, Lei Lin, Wei Lu and Yu Meng, "Landsat time series clustering under modified Dynamic Time Warping," 2016 4th International Workshop on Earth Observation and Remote Sensing Applications (EORSA), Guangzhou, 2016, pp. 62-66.

[10] Itakura F. Minimum prediction residual principle applied to speech recognition[J]. IEEE Transactions on Acoustics Speech and Signal Processing, 1975, 23(1): 67-72.

[11] Li Zhipeng. Research on integrated navigation method based on fusion algorithm [D]. Taiyuan: North University of China, 2015




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