Study on Geomagnetic-Matching Technology Based on ICP Algorithm

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Abstract: ***ICP (Iterative Closest Point) is a kind of image matching algorithm presented by Besl and McKay, Chen and Medioni and Z.Zhang at the same period [1]. Proposed algorithm was put forth in the image alignment, position estimation and other image processing algorithms which have been widely used especially in terrain match and gravity match, the aim is to improve the current existing basic navigation system INS (Inertia Navigation System) since INS is able to provide a real-time navigation information with good short-term accuracy, however the errors accumulates with time, to solve this, GPS (Global Positioning System) was introduced but still cannot correct this because it cannot work in the absence of satellite, also Terrain matching even though gives position information which is helpful for vehicle safety, but still doesn't work well when the vehicle sails on water. To correct INS errors we propose the new aided navigation system using ICP algorithm with real-time measurement data and computer simulations.***

Keywords: GPS, ICP, Image Processing, INS.

1. Introduction

ICP algorithm is one of the Image processing related algorithms, it as from the nearest point of the geomagnetic intensity contour line of correspondence, by taking the extreme value of correlation function to determine the conversion of data form into the model form and repeated iteration as the objective function decreases gradually. The specific process is to generate the magnetic field strength contour and extract values of the magnetic sensor acquisitions, the contour from the INS output location nearest point as the corresponding point in the digital reference geomagnetic map, and then measure the smallest significance in the objective function to find the optimal transformation of inertial position output, Besl's Method [2] is to densely sample the quaternion of unit sphere, and it can compute the complete set of local minimums with little error probability, but the computation is too large. Chengxiang Liu[4] uses random rotation and translation to reduce computation, but the randomicity is so strong that the best solution cannot even be found sometimes.

In this paper, the transformation is achieved through constant iteration, the INS position eventually transformed output value as the best match for alignment correction inertial navigation system as shown in Figure 1 and Figure 2.

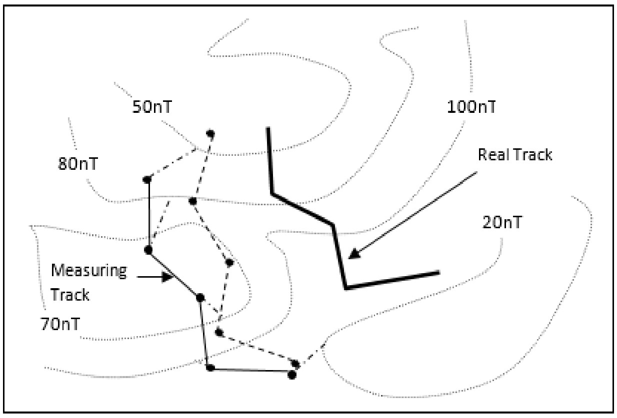

Figure 1: ICP algorithm iteration process

A geomagnetic field vector in the motion, such as the thick solid line shown in true position five measurement points, and the output position of the inertial system is also shown, corresponding to the output sequence of the magnetic sensor is a magnetic field (50, 80, 70,100,20) (in nT, the numerical size represents geomagnetic outliers). The matching process finds the contour firstly and field sequence (50,80,70,100,20) in geomagnetic map, shown by dotted lines, and then looks at the contour of the nearest output INS corresponding point, and finally the inertial trajectory rigid transformation to increase with the recent trajectory of the transformed corresponding point correlation properties, which completed the first iteration of the process, shown in Figure1, the dotted line represents the first conversion of INS after the results. By repeating the above process, INS will gradually converge to the true trajectory track as shown in Figure 2.

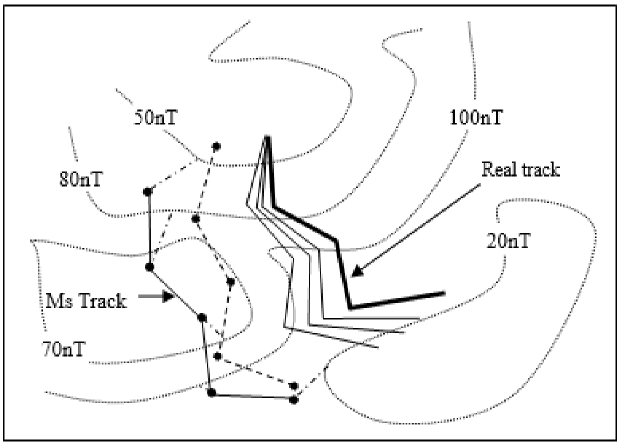

Figure 2: ICP iterative algorithm to track the real process

It is worth noting that the above only consider heading error INS and initial position error, but because of the carrier drift in matching section heading and position drift, The final result of the iteration may not be entirely identical to the actual track, but also the presence of the magnetic noise can also cause the convergence between measured track and the real track.

In addition, the geometry of the nearest corresponding contour point and the actual track and measure the track are not similar, but with the iterative process, which will gradually increase the degree of similarity.

Below is the geomagnetic matching algorithm flow chat based on ICP.

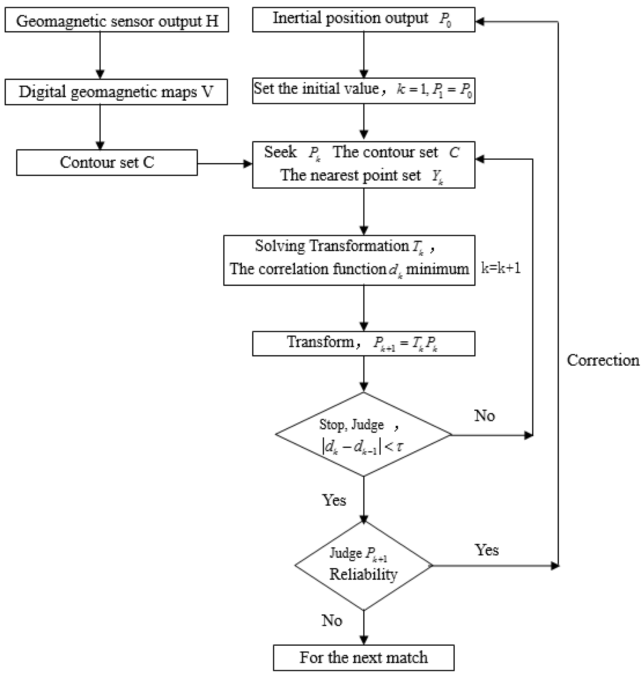

Figure 3: ICP geomagnetic matching algorithm process

2. Analysis of ICP Algorithm

In ICP algorithm, it can be seen that the real track is obtained by measuring the track of the rigid transformation, so the algorithm is the premise of measuring track with geometric similarity with the real track, so under these circumstances can be met or approximated to meet the required conditions, by the following detailed analysis.

A vector at initial time $t=0$, at the initial position $S_0=(X_0,Y_0)$, initial speed V_0, heading angle α, initial position error $\Delta S_0=(\Delta X_0,\Delta Y_0)$, initial velocity error ΔV_0, gyro drift δ, as shown in Figure 4 below;

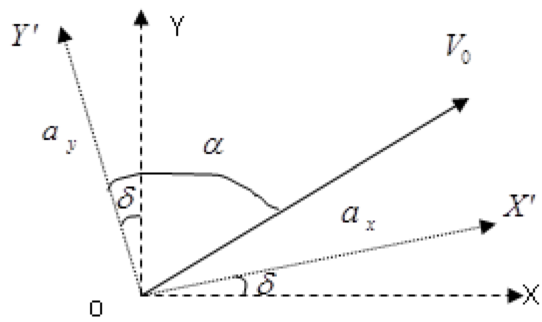

Figure 4: The relationship between actual and measured track

Where $X'OY'$ are the coordinate of computer inertial navigation system, XOY coordinate of the local geographical coordinates, INS located at $X'Y'$ axis acceleration Inputs a_x,a_y, noise as σ_x,σ_y,

Inertial system output equation is:

$$\begin{cases} X'=\int_0^t[\int_0^t a_x dt+V_0\sin\alpha]dt+X_0 \\ Y'=\int_0^t[\int_0^t a_y dt+V_0\cos\alpha]dt+Y_0 \end{cases} \tag{1}$$

The actual trajectory vector is:

$$\begin{cases} X=\int_0^t\{[\int_0^t[(a_x+\sigma_x)\cos\delta-(a_y+\sigma_y)\sin\delta]dt+(V_0+\Delta V_0)\sin(\alpha-\delta)\}dt+X_0+\Delta X_0 \\ Y=\int_0^t\{[\int_0^t[(a_y+\sigma_y)\sin\delta+(a_y+\sigma_y)\cos\delta]dt+(V_0+\Delta V_0)\cos(\alpha-\delta)\}dt+Y_0+\Delta Y_0 \end{cases} \tag{2}$$

When excluding the initial velocity error vector and acceleration noise, $\Delta V_0=0$, $\sigma_x=\sigma_y=0$, equation (2) can be simplified as:

$$\begin{cases} X=\int_0^t\{\int_0^t[a_x\cos\delta-a_y\sin\delta]dt+V_0\sin(\alpha-\delta)\}dt+X_0+\Delta X_0 \\ Y=\int_0^t\{\int_0^t[(a_y\sin\delta+a_y\cos\delta]dt+V_0\cos(\alpha-\delta)\}dt+Y_0+\Delta Y_0 \end{cases} \tag{3}$$

Further More:

$$\begin{pmatrix} X \\ Y \end{pmatrix}=\begin{pmatrix} \cos\delta & -\sin\delta \\ \sin\delta & \cos\delta \end{pmatrix}\begin{pmatrix} X'-X_0 \\ Y'-Y_0 \end{pmatrix}-\begin{pmatrix} X_0+\Delta X_0 \\ Y_0+\Delta Y_0 \end{pmatrix} \tag{4}$$

Thus it can be seen that the real track can have output by inertial system steps to go through translation - rotation - translation steps to obtain the measuring path and the actual track with geometric similarity. That is the basis of using ICP algorithm. In the presence of the initial velocity error and acceleration noise, the true trajectory will produce deformation and drift.

3. Simulation Analysis

Here, according to the theory of the geomagnetic matching, is tested in a specific region of the earth's geomagnetic field data in a certain area the grid resolution of about 500m x 500m. The real path and motion vector set in advance, the inertial navigation output data from the inertial navigation equations, measurement data of magnetic sensor is composed of the real value of the magnetic field vector position plus white noise. The initial conditions of the simulation are shown in the following table.

Table 1: carrier motion model parameters

The Initial Position	Longitude	110.0952°
	Latitude	42.0500°
The Initial Velocity	X-Axis	6m/s
	Y-Axis	8m/s
Acceleration	X-Axis	$0m^2/s$
	Y-Axis	$0m^2/s$

Table 2: INS output parameter

INS initial position error	1000m	
INS initial position error Angle	120°	
Inertial acceleration error	X-Axis	$10^{-4}m^2/s$
	Y-Axis	$10^{-4}m^2/s$

Table 3: Geomagnetic sensor parameters

Sampling interval	10s
Number of samples	20times
Magnetic sensor noise	1nT

From the above parameters given in Table 1 and Table 2, we can determine the state of motion vectors during the matching period, shown in Figure 5. The solid line represents the actual movement of the carrier track, a dotted line represents the output obtained by the inertial systems track, star point which indicates the sampling instant of the output of the reference position of INS.

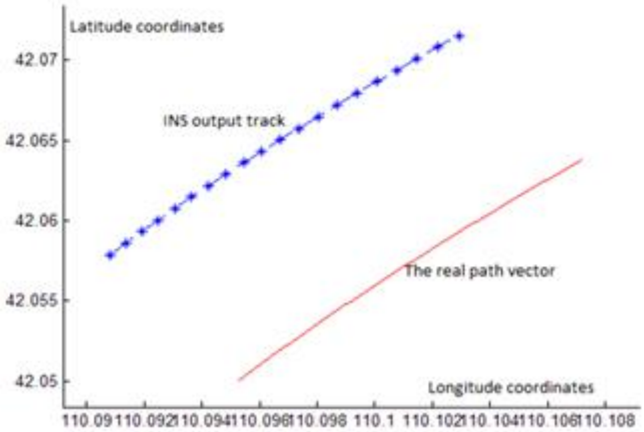

Figure 5: Carrier trajectory under given conditions

Figure 6 shows how the geomagnetic matching algorithm based on the ICP, the trajectory gradually converge to the true track process. Simulation results show that under these conditions the final match to reach the positioning error is 300m (CEP). Of course, with the change of the initial conditions, the matching error will change, in which the key influence factors including noise intensity, magnetic sensor INS initial error and sampling frequency. The following discusses its influence on the positioning error

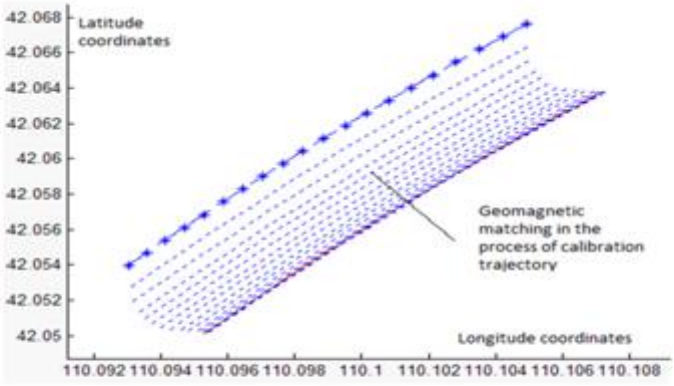

Figure 6: Geomagnetic matching algorithm simulation

Under the simulation conditions of Table 1 to Table 3, in order to investigate the overall matching within an area, it is necessary to change the direction of movement of the carrier. If the carrier speed is 10m / s, while the velocity direction random, statistical properties can be obtained by several experiments. Similarly, INS initial output position should be in the range of CEP to generate random error vector in the initial position. Other conditions remain unchanged, the simulation results are shown in Table 4, where the first column represents the carrier initial position matrix in the magnetic map coordinates. In each experiment, the direction for vehicle speed $\pi/3$, $2\pi/3$, ……, 2π, and in each carrier of the initial position of 30 randomly generated INS initial output position, mean of all the simulation results as the matching error.

Table 4: Characteristics of geomagnetic map of different locations and matching simulation error

Initial Position	Geomagnetic variance (nT)	Geomagnetic roughness (nT)	Correlation properties	Matching error (m)
(80, 40)	10.12	7.70	0.6516	446
(80, 80)	45.12	12.13	0.9401	333
(80, 100)	20.27	5.91	0.8570	482
(160, 40)	84.34	67.63	0.6087	359
(160, 80)	74.54	43.04	0.8267	430
(160, 100)	60.00	40.55	0.6417	484
(200, 40)	48.94	37.77	0.6352	466
(200, 80)	20.26	9.02	0.8385	310
(200, 100)	83.81	73.76	0.5952	446
(280, 40)	72.72	43.67	0.7864	436
(280, 80)	122.88	97.67	0.5984	259
(280, 100)	182.83	52.92	0.8958	332

As can be seen from Table 4, if the geomagnetic matching results are reliable, the positioning accuracy of about 400m. On the basis of the original error 1000m visible on the geomagnetic matching can effectively correct INS errors and improve accuracy. In different areas, geomagnetic matching calibration error is not the same, which has an important relationship with the magnetic characteristic of the region. In general, the greater the variance of geomagnetic field, surface roughness increases, the matching error is small, the table also reflects the conclusion briefly. Through the simulation test, the geomagnetic matching algorithm based on ICP has certain applicability in practice. But as the carrier of the initial position, inertial navigation outputs relative changes in the initial position and magnetic map location, as well as the existence of the magnetic field sensor noise, the matching algorithm will fail, and even cause the increase in errors, so there is a need to take some measures to improve the matching algorithm.

4. Conclusion and Recommendations

Geomagnetic navigation is a kind of geophysical field navigation, is a new kind of navigation technology developed in the 21st century, attracting the attention of countries all over the world [3]. This topic is based on the requirements of concealment and the high accuracy of submarine, its core is to provide the data calculation method for geomagnetic navigation system. Geomagnetic navigation system composed of inertial navigation system, the magnetic sensor, the digital geomagnetic map database, the geomagnetic matching algorithm and comprehensive calibration algorithm.

With the above discussion, the ICP algorithm is based on the INS error analysis. Error INS is mainly caused by two factors. First, because of the presence of various noise measurement tracks after conversion which is generally not precisely aligned to the real track, ICP algorithm requires minimum variance optimization method, and the objective function is based on the entire track error, for each specific track points not guaranteed to be optimal. On the other hand, due to the algorithm itself, can also cause the final alignment error.

From the above analysis we can see that although ICP algorithm has some applicability, but there are still some shortcomings and proposed directions and ideas for improvement which includes the following:

1）The magnetic field data preprocessing

Due to the various reasons, the data collected in the magnetic sensor can be contaminated to some extent, which brings some difficulties during further match locations. The commonly used statistical method to eliminate outliers, between the space is not detailed here, can refer to reference [5].

2）Reducing the impact of false nearest point

The essential causes of false location is due to the false nearest point, false nearest point is due to the similarity of geomagnetic map features, which often is inevitable, so we can reduce the influence of the accuracy of the algorithm.

3）Increased geomagnetic information

The fundamental reason of false nearest point is the presence of a magnetic field and the geomagnetic elements characteristics of the same region, if the increase in the earth's magnetic field information, this situation can be avoided, so as to improve the accuracy of the algorithm, such as earth's magnetic field direction and magnetic field gradient etc.

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