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Research of Digital Depth Model Interpolation Methods

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Abstract

This article introduces the methods of moving surface fitting and distance-weighted on dealing with digital depth model interpolation, and analyzing their characteristic. Then the article provides a new method which uses distance-weighted to interpolate as a supplement after using moving surface fitting. The method can overcome the weakness that the constraint condition could not be satisfied in some area when simply using moving surface fitting. The result shows that the new method can get higher accuracy and better impression, which increases the efficiency greatly.

1. Introduction of DDM interpolation

Digital depth model (DDM) is a kind of digital expression of seabed terrain, which makes up for a lack of contour. It can not only describe the undulate and varied seabed terrain, but also be fit for the relevant mathematical analysis and simulation. Establishing DDM with high quality makes a great contribution to the ocean geographic information system and autonomous navigation [1]. Interpolation is the core of DDM which runs through each link such as quality assessment, precision evaluation and analysis application. Grid DDM takes advantage of known water depth data to interpolation, and creates a regular grid DDM that has a greater density. However, owing to the limitation of observation means and information resource, usually only the discrete and irregular sounding sampling points and limited depth contour can be obtained. Therefore, to study DDM interpolation methods with high quality has an important value both in theory and reality.

DDM interpolation takes advantage of some adjacent water depth data sampling points to figure out the water depth data of undetermined points,

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thus obtaining regular grid DDM which has a high density. It belongs to interpolation problem in mathematics. Any kind of interpolation method is on the basis of the continuity and smooth of the undulate and varied initial seabed terrain, which is to say that only when the adjacent data points have great correlation can the water depth data be obtained from them.

Most of interpolation methods are based on the hypothesis: any object is related to other objects, while the closer one has a greater correlation than the farther one [2]. It means the closer the points are, the greater correlation they have, from which different kinds of interpolation method are derived. Currently, the frequently-used interpolation methods are distance-weighted method, moving surface fitting method, spline method, neural network method, Kriging method, VoronoiCells method and so on [3]. This paper combines moving surface fitting method to distance-weighted methods, thereby the interpolation result is more fit for the real seabed terrain.

2. Research of DDM interpolation methods

2.1 Pretreatment process

The pretreatment of the sampling points which are searched should be carried out before calculating the water depth of undetermined points.

The pretreatment method used in this paper is as follows:

(1). Calculating the number of sampling points in the circle whose centre is the undetermined point, and calculating the difference of elevation dh of the maximum point and the minimum point in the circle. Supposing dh changes uniformly and is located on the side of the circle, besides, the allowable interpolation error is 1m, and $ds=(1\times R)/dh$ can be obtained (R is the radius of the circle).

(2). If there is a sampling point whose distance to the undetermined point less than or equal to ds in the circle, using the closest water depth to replace the depth of undetermined point, otherwise going to step (2) [4].

(3). If the number of sampling points is more than or equal to 8, using moving surface fitting method to interpolate.

(4). If the number of sampling points is less than 8, using distance-weighted method to interpolate.

The pretreatment process divides sampling points into three classes, and the interpolation methods depends on the different distribution characteristics. The pretreatment process could increase both the calculation speed and the interpolation precision efficiently, thus increasing the efficiency of modeling

2.2. Moving surface fitting method

The moving surface fitting method adopts the discrete water depth and contour data in the vector chart depots to execute surface fitting, thereby obtaining the water depth data of any geographic coordinate. This method is very flexible and precise. Besides, it has high efficiency and robustness. Moreover, the calculation is easy and occupies little internal memory.

The interpolation process of moving surface fitting is as follows:

Establishing the regular grid spatial structure which covers all of the regions, and the grid size is depended on DDM modeling requirement.

(1) Seeking the sampling points in the circle whose center is the undetermined point P and radius is R. All the data that are in the circle are selected and used. The number of the points is on the basis of adoptive local fitting function. If the number is not enough, increasing the value of R.

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(2) In consideration of convenience of calculation, for all the grid point $P(x_p, y_p)$ of DDM, moving the origin of coordinate to this point.

$$\begin{cases} \overline{X}_i = X_i - X_p \\ \overline{Y}_i = Y_i - Y_p \end{cases}.$$

(3) The fitting surface which is fit for the seabed terrain is often lower multinomial (quadratic or cubic). This paper chooses quadric surface as the fitting surface, and the function is as below:

$$Z = AX^2 + BXY + CY^2 + DX + EY + F,$$

X 、 Y 、 Z are the coordinate value of each sampling point.

A 、 B 、 C 、 D 、 E 、 F are undetermined parameters.

The corresponding error function is:

$$v_t = \overline{X}_t^2 A + \overline{X}_t \overline{Y}_t B + \overline{Y}_t^2 C + \overline{X}_t D + \overline{Y}_t E + F - Z_t.$$

The error function which is obtained from n data is:

$$v = MX - Z,$$

Among it

$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_n \end{bmatrix} \quad X = \begin{bmatrix} A \\ B \\ \vdots \\ F \end{bmatrix} \quad Z = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_n \end{bmatrix},$$

$$M = \begin{bmatrix} \overline{X}_1^2 & \overline{X}_1\overline{Y}_1 & \overline{Y}_1^2 & \overline{X}_1 & \overline{Y}_1 & 1 \\ \overline{X}_2^2 & \overline{X}_2\overline{Y}_2 & \overline{Y}_2^2 & \overline{X}_2 & \overline{Y}_2 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \overline{X}_n^2 & \overline{X}_n\overline{Y}_n & \overline{Y}_n^2 & \overline{X}_n & \overline{Y}_n & 1 \end{bmatrix}.$$

According to the least square method, the solution of the quadric modular is [5]:

$$X = (M^T P M)^{-1} M^T P Z,$$

Among it P is weight matrix. Whereas the difference in degree of correlation depends to the difference in distance of sampling to undetermined point, the paper uses different weight P_i. The n sampling points constitute a $n \times n$ matrix. Because the origin of coordinate is moved to the grid point $P(x_p, y_p)$ of the DDM, so there is $\overline{X}_p = \overline{Y}_p = 0$, and the coefficient F is the depth value Z_p of P.

2.3 Distance-weighted method

In the moving surface fitting method, the quadric surface function is a local function, so there are some limitations. There are 6 unknown numbers in the fitting surface function, which means the method needs at least 6 points that are uniform distributed around the undetermined point. The best condition is to have 8 or more than 8 uniform distributed points. It is obvious that moving surface fitting has high requirement of sampling points which are not easy to satisfied . Besides, for the area where the contour is very few and on the boundary, there are few sampling points and the sampling points incline to one side. Aiming at this situation, this paper combines moving surface fitting method and distance-weighted method to solve this problem.

Distance-weighted method adopts calculating the weighted means of the points in the circle whose center is the undetermined point and radial is R to obtain the depth. This method could ignore the distribution of undetermined points and only use the weighting coefficients. It is obvious that the method is easy to be achieved. The radial R can be got from the following empirical formula [6]:

$$R = \sqrt{k \frac{A}{n\pi}},$$

A is the area which includes all the dispersed water depth data. n is the number of dispersed water depth data. k is the average value of evaluated points, and it is usually be set as 7.

Assuming the coordinate of the undetermined point P is (x_p, y_p, z_p), and sampling points in the

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neighborhood are $(x_i, y_i, z_i)(i = 1, 2, \cdots, n)$, among which n is the number of sampling points. p_i is the weight of the sampling point i, and d_{ki} is the distance of undetermined point and sampling point. So the interpolation formula is [7]:

$$z_p = \frac{\sum_{i=1}^{n} p_i z_i}{\sum p_i},$$

Among it

$P_i = \frac{1}{d_{ki}^2}$, $d_{ki} = \sqrt{(x_i - x_p)^2 + (y_i - y_p)^2}$.

3. Simulation results and analysis

Evaluating DDM precision mainly means analyzing the interpolation error. This paper uses checking point method to evaluate. Checking point method adopts three points whose coordinate have been known and the control point to check the DDM data. Calculate the interpolation water depth of these points, and comparing the interpolation water depth with the real water depth, thus obtaining the D-value. Calculate the mean square error, maximum error and average error [8].

This paper evaluates the precision of moving surface fitting method and the method which coordinates distance-weighted method with it. The data used in the experiment comes from some sea area. Figure 1 is the result of using moving surface fitting method alone. Figure 2 is the coordinated method.

Coordinate		Depth(m)	Moving surface fitting method	
X(m)	Y(m)		Depth(m)	Error(M)
5 XX 43	3 XX 64	28.601	23.473	-5.128
5 XX 41	3 XX 45	43.528	43.913	0.385
5 XX 56	4 XX 81	36.142	35.634	-0.508
6 XX 23	3 XX 12	25.780	29.074	3.294
6 XX 38	4 XX 56	36.648	38.951	2.303
5 XX 53	3 XX 92	40.194	40.217	0.023
6 XX 84	3 XX 79	28.814	25.176	-3.638
5 XX 92	4 XX 92	25.906	26.407	0.501
6 XX 89	3 XX 17	26.719	27.484	0.765
5 XX 97	4 XX 58	28.436	31.023	2.587
Mean square error			2.172	
Maximum error			5.128	

Fig. 1 Result of using moving surface fitting method

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Coordinate		Depth(m)	Coordinated method	
X(m)	Y(m)		Depth(m)	Error(m)
5 XX 43	3 XX 64	28.601	28.938	0.337
5 XX 41	3 XX 45	43.528	43.874	0.346
5 XX 56	4 XX 81	36.142	35.634	-0.508
6 XX 23	3 XX 12	25.780	27.065	1.285
6 XX 38	4 XX 56	36.648	35.289	-1.359
5 XX 53	3 XX 92	40.194	40.217	0.023
6 XX 84	3 XX 79	28.814	26.943	-1.871
5 XX 92	4 XX 92	25.906	26.207	0.301
6 XX 89	3 XX 17	26.719	27.484	0.765
5 XX 97	4 XX 58	28.436	27.823	-0.613
Mean square error			0.741	
Maximum error			1.871	

Fig. 2 The coordinated method

It is obvious that the coordinated method has lesser error. It is because moving surface fitting method needs a group of water depth data which should uniformly distributed in all the direction around the undetermined point. Using the data on one side could lead to greater error of the DDM seabed surface equation to the real depth. However, using distance-weighted method to supply it could overcome the error problem which comes from the high requirement that moving surface fitting method needs. Therefore, the method proposed in this paper fully uses the characteristics that different sampling density should correspond different interpolation method.

4. Summary

This paper studies the characteristics of moving surface fitting method and distance-weighted and proposed a method which coordinate both of the methods to solve DDM modeling problem. The coordinated method overcomes the weakness that the constraint conditions of sampling points in some area of moving surface fitting method are difficult to satisfied , and increases the precision efficiently. In the real DDM, how to choose the interpolation method should depend on the seabed terrain [9], the way of selecting points and the density of sampling points to achieve great modeling effect.

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