Research on the Surface Extraction of the Point Cloud Data in Marine Surveying and Mapping

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ABSTRACT: This paper firstly made analysis of the points, lines and surfaces with special curvatures in point cloud data information and classified the points according to the three eigenvalues obtained through analysis matrix. And then, it simplified the point cloud data. Data simplification was completed according to distance, surface variation, and curvature. At last, it screened, removed and classified the data based on the least square method applied in the fuzzy clustering analysis in local domain, so as to fit the point cloud surface and improve the extraction precision of the entire data.

Keywords: point cloud data; marine surveying and mapping; extraction; simplify; aggregate

1 INTRODUCTION

Marine surveying and mapping includes marine surveying and marine mapping. It shows the geographic conditions of ocean based on the obtained content, quality and features of point cloud data. Marine surveying and mapping data can provide foundation and materials for conducting various marine activities. Extraction of data surface mainly includes screening eigenvalues and simplifying point data. The simplification process is to complete point cloud data deletion and integration based on clustering analysis model.

![Planar point Kink mark point Boundary point Focal point](Image)

Figure 1. Correlated ellipsoid shapes corresponding to different types of points.

Measurement can be conducted to oceans, rivers, lakes and neighboring land. Marine data includes seachart data, submarine topographical data and seal-level information data. It includes surveying and mapping of coastline, elevation, settlement place, and island. With the development of computer simulation technology, real three-dimensional marine model can be established. The geometrical characteristics of marine information are the elements describing physical and spatial features and can play a critical role in extracting the features of the points, lines and surfaces correlated to point cloud data.

2 SELECTION OF POINT CLOUD DATA FEATURES

Data forms of marine observation points can express the mechanics and physical properties of marine variation. Analysis can be conducted according to the points, lines and surfaces with special curvatures in information. Points in the point cloud data formed by marine observation data contain differential characteristics, such as curvatures or normal vector, among which characteristic line is the boundary of two different regions. Neighborhood covariant matrix of observation points was established and, data points were classified. Three eigenvalues, \( \lambda_1, \lambda_2 \) and \( \lambda_3 \), were obtained through analysis matrix. For the planar point in Figure 1: \( \lambda_1 = \lambda_2 \) and \( \lambda_3 = 0 \). For the kink mark point: \( \lambda_1 = \lambda_3 \) and \( \lambda_1 + \lambda_2 \approx \lambda_3 \). For the boundary point: \( \lambda_3 = 0 \) and
2 \times \lambda_1 \approx \lambda_2. For the focal point: \lambda_1 \approx \lambda_0 \approx \lambda_2. As shown in Figure 1, the point data types of kink mark point, boundary point, inflection point and planar point were obtained respectively.

For some point on the point cloud surface, different principal curvatures are expressed as \( K_1 \) and \( K_2 \). Gaussian curvature can be expressed as \( K = K_1 \times K_2 \), referring to the total curvature of some point. If \( K > 0 \), the surface is bulged. If \( K < 0 \), there’s saddle point on the surface. If \( K = 0 \), the surface is flat. Average curvature is marked as \( H = (K_1 + K_2)/2 \), reflecting the degree of crook of some point on the surface—the mean curvature.

3 SIMPLIFICATION AND EXTRACTION OF POINT CLOUD DATA

3.1 Simplification of point cloud

The simplification of point cloud data is to delete ‘redundant points’. These points have no major effect on the reconstruction of geometrical shape of surface. We replace some fine points with sparse points. These confirmed sparse points can maintain the geometrical features and visual features of original point sets. According to control of variable values, the simplification process of points can be divided into distance, surface variation and curvature as follows:

(1) Distance

While screening point cloud distance, if the distance between two points in one sentence is less than the critical value of the minimum distance, the points can be deleted. However, this method cannot manifest the variation of point cloud surface. The distance from one point to local surface can be used to measure whether the point can be deleted. Measure variation of ‘redundancy’ according to the distance from the point to the MLS surfaced formed by its movement, so as to simplify point cloud data. In local height data of point cloud, the simplification error of some point \((x, y)\) can be expressed as:

\[
H(x, y) - (rS)(x, y)
\]

\(H(x, y)\) refers to the height of point \((x, y)\) in point cloud while \((rS)(x, y)\) refers to the height of point \((x, y)\) in point cloud after simplification.

(2) Surface variation

Surface variation can manifest the fluctuant change of point cloud surface and show that offset extent along normal direction on tangent plane estimates the deviation degree of data point from horizontal plane according to deviation. For point deviation concentrated in local points, the estimation can be made according to the offset from plane obtained through the least square method. And we manage data simplification on the basis of surface discrete curvature variation. In specified area, less surface variation leads to lower average curvature and, more surface variation leads to higher average curvature. Curvature variation is related to the number of selected points.

(3) Curvature

Taking the geometrical features of point cloud into consideration, more points are required for supporting areas with higher curvature. Due to the unknown property of point cloud surface, the study of curvature can be conducted according to estimate method. And we complete clustering of neighboring points based on the selection of points under clustering model, so as to realize point cloud simplification.

3.2 Clustering extraction of point cloud data

Set \( p = [a \ b \ c \ d]^T \) as the parameters of \( ax + by + cz + d = 0 \) on point cloud plane and there’s \( a^2 + b^2 + c^2 = 1 \), then the clustering error can be described as follows:

\[
\varepsilon(V_i) = \sum_{p \in V_i}((V_i^T M_p V_i)) = V_i^T(\sum_{p \in V_i} M_p)V_i
\]

Among which, \( M_p \) refers to the symmetric matrix of \( 4 \times 4 \).

\[
M_p = pp^T = \begin{bmatrix}
    a^2 & ab & ac & ad \\
    ab & b^2 & bc & bd \\
    ac & bc & c^2 & cd \\
    ad & bd & cd & d^2
\end{bmatrix}
\]

As long as the distance from some point to related plain in clustering is less than the threshold value after simplification, the point can be deleted. Clustering center \( V_i \) shall be used.

![Figure 2. Clustering extraction of point cloud.](image)

4 CLUSTERING ALGORITHM ANALYSIS OF POINT CLOUD DATA

As shown in Figure 2, four hierarchies can be obtained from the point cloud data in marine data: universal set, subset, type and element.

4.1 EM clustering algorithm

EM clustering algorithm is a clustering method taking
the MLE (Maximum Likelihood Estimation) of parameters as reference. MLE method can be applied to estimate incomplete data. Therefore, EM clustering algorithm can be well applied in incomplete field data.

Assume the set can be described as follows:

\[ Z = (X, Y) \]

Among which \( X \) refers to data obtained through observation and \( Y \) refers to data that cannot be observed. Then, \( Z = (X, Y) \) can include complete data while \( X \) and \( Y \) are incomplete data.

Assume the probability density of \( Z = (X, Y) \) is:

\[ p(X, Y / \Theta) \]

Among which \( \Theta \) refers to estimated parameter. Based on the MLE of \( \Theta \), the process of \( L(X, \Theta) \) which is the likelihood function of \( Z \) can be obtained:

\[ L(X, \Theta) = \log p(X, Y / \Theta) = \int \log p(X, Y / \Theta) dY \]

There are two steps included in EM clustering algorithm:

1. Log-likelihood function of maximized incomplete data is as follows:

\[ Lc(X, \Theta) = \log p(X, Y / \Theta) \]

2. Assume the estimate of \( \Theta \) after \( t \) times of iteration is \( \Theta(t) \). The definition of the expectation of the log-likelihood function obtained after \( t+1 \) times of iteration can be given as follows:

\[ Q(\Theta \setminus \Theta(t)) = E \{ Lc(\Theta; Z) \setminus X; \Theta(t) \} \]

Then reach a new definition of \( \Theta \) by maximizing \( Q(\Theta \setminus \Theta(t)) \).

4.2 K-means clustering algorithm

The algorithm process of K-means clustering algorithm is as follows:

1. Randomly select \( M \) points in space as clustering centers.
2. Apply principle of proximity to fold the objects which are the closest to clustering centers and obtain clusters formed by different clustering centers.
3. Apply iteration method and vary clustering centers to obtain the optimal results.

In K-means clustering algorithm, closer distance to clustering center represents higher similarity to obtain clusters formed by clustering centers.

4.3 Clustering based on grid density

The algorithm principles of clustering based on grid density can be described as follows according to different densities:

1. Randomly find clustering clusters in convex profile of density.
2. Screen clusters with low density and form high-density clustering clusters.

Clustering algorithm is to classify and fold objects with similarity to reasonably distribute and arrange complex objects. Each folded object can construct a set. As a result, each set contains similarity.

4.4 Fuzzy clustering algorithm

Take fuzzy clustering algorithm as an example. At first, see Figure 4 for fuzzy clustering patterns.

Figure 4. Hierarchical clustering mode patterns.

Figure 5 is the surface diagram of point cloud data formed without clustering feature extraction.
Fuzzy clustering is to cluster in accordance with the least square method. Square law (also called the method of least square) is a mathematical optimization technology. It seeks for the best function match of data by minimizing the quadratic sum of error. Application of the least square method can obtain unknown data in a convenient way and minimize the quadratic sum of the error between obtained data and actual data. In the normal vectors obtained in each point with precondition of clustering, some point at the inside of object while some point at the outside. Therefore, uniformization must be conducted on the obtained normal vectors. And high-order surface can be expressed as:

$$z = \sum_{j=0}^{0} \sum_{i=0}^{0} a_{i,j-1} x^i y^{j-1}$$

For a given data array $\left(x_q, y_q, z_q\right) q = 1, 2, ..., N$, the equation of fitting surface can be expressed as:

$$Q = \min_{q=1}^{N} \left[ z_q - \sum_{j=0}^{0} \sum_{i=0}^{0} a_{i,j-1} x^i y^{j-1} \right]$$. The minimum value of $Q$ was taken and $\frac{\partial Q}{\partial a_{i,j-1}} = 0$ was met to obtain the analytic expression of fitting surface and complete the fuzzy clustering of point cloud. After extracting the surface features of the point cloud shown in Table 1 according to Matlab, the point cloud data graph was obtained. Then, comparison was completed between the point cloud data surface chart formed by extracting the features without clustering as shown in Figure 6 and the obtained point cloud data graph.

![Figure 5](image1.png)

**Figure 5.** Surface diagrams of point cloud data formed without clustering feature extraction.

![Figure 6](image2.png)

**Figure 6.** Point cloud data obtained through fuzzy clustering surface extraction algorithm.

Calculation was made on the insertion, modification and division of the control points of clustered nodes while weight factors were modified to correct curve shapes. This paper conducted experimental comparison on the scattered point cloud data with different surface features and reached conclusions about which surface features can well extract points, lines and surface features in accordance with fuzzy clustering algorithm. The algorithm given in this paper can well solve the problem in extracting points, lines and surfaces from objects with complex surfaces.

Content, quality and features of marine point cloud data can manifest the geographical conditions of oceans. The surface extraction of the point cloud data in marine surveying and mapping will first select data features. It completes data simplification through clustering algorithm. Fuzzy clustering is to calculate the insertion, modification and division of control points. This paper firstly analyzed surface fitting of point cloud data by the least square method applied in fuzzy clustering analysis. And this clustering method modifies curve shapes by calculating the insertion, modification and division of control points and modifying weight factors, so as to obtain better extraction of points, lines and surfaces of marine surface objects for fitted surfaces.

5 CONCLUSIONS

Content, quality and features of marine point cloud data can manifest the geographical conditions of oceans. The surface extraction of the point cloud data in marine surveying and mapping will first select data features. It completes data simplification through clustering algorithm. Fuzzy clustering is to calculate the insertion, modification and division of control points. This paper firstly analyzed surface fitting of point cloud data by the least square method applied in fuzzy clustering analysis. And this clustering method modifies curve shapes by calculating the insertion,
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