GIS remote sensing image 3D reconstruction with optimization of affine invariant

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Abstract
According to the low effect of present 3D scene reconstruction algorithm in reconstruction of GIS remote sensing image 3D scene, this paper proposes a GIS remote sensing image 3D modeling algorithm based on cultural surface model and the improved RANSAC algorithm. First, use the Bezier curve to fitting curve of cultural, and reduce the sum of the distances between points to the corresponding point on the curve. And then use the point cloud characteristics of point pairs, and a point cloud data set as reference, to solve the two point cloud data sets between the parameters of geometric transformation matrix, and eliminate false matching points based on the RANSAC algorithm, to estimate the transformation matrix. Finally by affine invariant to constraint the sample extracted by RANSAC algorithm, to reduce the sample quantity, thereby increasing the speed of RANSAC registration algorithm. Simulation experiments show that the proposed GIS remote sensing image 3D modeling algorithm based on the culture surface model and improved RANSAC algorithm has very good modeling effect, and the improved RANSAC algorithm efficiency has been greatly improved.
Key words: CULTURAL SURFACE, RANSAC ALGORITHM, THE BLOCK BEZIER CURVE, POINT CLOUD DATA SETS, AFFINE INVARIANT

Introduction

As quickening the urbanization, many cities are developing the real estate industry. Real estate developers also have sprung up, the number of new building construction and development also has increased dramatically. Previous real estate marketing model has been unable to meet the demand of real estate developers and property buyers in the information age, such as: the production of sand table model, floor door model figure display, media propaganda and developers between the example that decorate, etc. [1]. At present, the traditional real estate marketing mode with the development of 3D visualization technology is gradually be replaced, combining application of 3D visualization technology and design concept gradually become a new marketing mode choice among developers [2]. Based on the improvement of 3D visualization technology to make up for the inadequacy of traditional real estate marketing mode, users in the use of 3D visualization technology shows the scenario can be free to browse, query, analysis, its immersive distinct visual effect, can speed up the real estate sales [3].

3D modeling is the research hotspot and difficulty in the field of 3D GIS, many scholars at home and abroad to do a lot of work in this field. Requicha put forward that modeling algorithm based on entity is a kind of method often used in the field of the computer aided design (CAD), it is a similar to the actual machining process modeling methods, such as cutting, drilling, etc. [4]. Hillyard and Braid take the geometric entities as physical framework, when the first frame in Free State, with loose connections. Points and edges respectively corresponding to the framework of nodes and connecting rod, and size information is the firmware for restraining and fixing framework [5]. Molennar put forward 3D vector formal data structure model, the model is a simple extension of 2D topological data model, four kinds of basic geometric elements such as its node, segment, border and surface as the basic types of graphics part, the relationship between geometric elements and object type is determined by the five principles [6]. Robert study on "building the world", and extract the three-dimensional structure of polyhedron (such as the cube and prism, etc.) from the target digital image in writing computer programs, and the shape of the object and the mutual spatial relations are described, his work started to understand the real world of 3D scene of machine vision for study [7]. KIM et al. to extract automatically from the city image building has carried on the related research [8]. HUERTAS et al. combine the shadow and perspective geometry theory to do the relevant research [9]. Quadratic spline curve is studied for the reconstruction of the interpolation algorithm by Mcallister [10]. Piecewise cubic curve interpolation is discussed in the application of curve reconstruction by Fritsch. The reconstruction of the surface, the Bezier surface is the typical representative of this aspect research which is proposed by Bezier. The method being equation is used to direct the target modeling, can accurately express some space entity, needs less memory and computing speed, and get the unique results [11]. Zhang Fan and others study the single station ground laser scanning point cloud modeling algorithm under the stereographic projection. Zheng Dehua and others study ellipsoid modeling algorithm under different space closed plane [12].

According to the need of 3D scene reconstruction, this paper puts forward a 3D modeling algorithm based on the culture surface model and improved RANSAC algorithm.

Cloud feature extractions of construction points based on the culture surface

The information of each point in the 3D model is the coordinate and the color of 3D points, cultural curve is composed of point. For such as shown a cultural curve of curve equation $f(x, y, z) = 0$, for its starting point as $point1$, end point as $point2$, its mathematical model can be expressed as a collection of all the points on the curve:

$$C = \{point(coord, color) \mid f(coord.x, coord.y, coord.z) = 0 \quad (1)$$

$$point1.x \le point(coord).x \le point.x\} \quad (2)$$

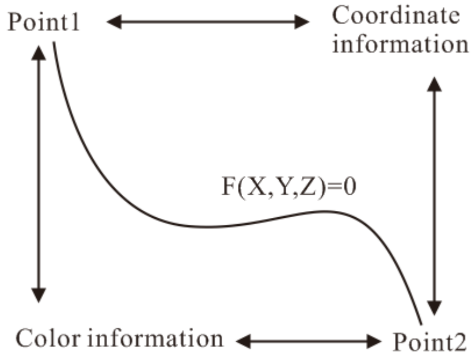

Figure 1. Cultural layer surface

Feature extraction of cultural curve is the process of expressing cultural curve equation, namely for curve fitting of known points. In this paper, use piecewise the Bezier curve to cultural curve fitting.

For a series of points $V_0, V_1, V_2, \ldots$ for fitting, if we want to with a Bezier curve $Q(t)$ to fit, need to compute the distance between fitting point to the corresponding point on the Bezier curve, if the distance is within a certain range ε, then think that fitting work is done.

For a given point V, the distance between it and the corresponding point on the curve is $dist = \| V - Q(t) \|$. Therefore, the fitting purpose is designed to minimize the distances between fitting points to the corresponding point on the curve. We use a function S as a standard for measuring, S is defined as equation (3).

$$S=\sum_{i=1}^{n}[d_i-Q(u_i)]^2 \qquad (3)$$

In the equation, d_i is the coordinate (x, y) of the fitting points, u_i is parameter values associated with d_i.

For the following derivation process, we have the following definition:

1) P_0 and P_3 is the first and the last control point, the conclusion shows they are the first and the last one point of fitting points;

2) $\hat{t}_1$ and $\hat{t}_2$ are respectively the unit tangent vector of points P_0 and P_3;

3) The other two control points P_1 and P_2 respectively:

$$P_1=\alpha_1\hat{t}_1+P_0 \qquad (4)$$

$$P_2=\alpha_2\hat{t}_2+P_3 \qquad (5)$$

For a fixed end control points of the Bezier curve, can change the coordinates of the second and third control points to change the shape of the Bezier curve, and thus the problem can be converted into finding a α_1 and α_2 to get the minimum S, thus has the following two equations:

$$\frac{\partial S}{\partial \alpha_1}=0 \qquad (6)$$

$$\frac{\partial S}{\partial \alpha_2}=0 \qquad (7)$$

Equation (3) is take into equation (6) and equation (7) and calculated, finally we can get equation (8) and (9).

$$(\sum_{i=1}^{n}A_{i,1}^2)\alpha_1+(\sum_{i=1}^{n}A_{i,1}\cdot A_{i,2})\alpha_2= \sum_{i=1}^{n}(d_i-(P_0B_0^3(u_i)+P_0B_1^3(u_i)+P_3B_2^3(u_i)+P_3B_3^3(u_i)))A_{i,1} \qquad (8)$$

$$(\sum_{i=1}^{n}A_{i,1}\cdot A_{i,2})\alpha_1+(\sum_{i=1}^{n}A_{i,1}^2)\alpha_2= \sum_{i=1}^{n}(d_i-(P_0B_0^3(u_i)+P_0B_1^3(u_i)+P_3B_2^3(u_i)+P_3B_3^3(u_i)))A_{i,2} \qquad (9)$$

In the equations, $A_{i,j}=\hat{t}_jB_j^3(u_i),\ j=1,2$.

Make the equation (8) and (9) sample, we get equation (10) and (11).

$$c_{1,1}\alpha_1+c_{1,2}\alpha_2=X_1 \qquad (10)$$

$$c_{2,1}\alpha_1+c_{2,2}\alpha_2=X_2 \qquad (11)$$

Then represent by matrix, namely

$$\begin{pmatrix}c_{1,1} & c_{1,2}\\ c_{2,1} & c_{2,2}\end{pmatrix}\begin{pmatrix}\alpha_1\\ \alpha_2\end{pmatrix}=\begin{pmatrix}X_1\\ X_2\end{pmatrix} \qquad (12)$$

Suppose that $\varsigma=\begin{pmatrix}c_{1,1} & c_{1,2}\\ c_{2,1} & c_{2,2}\end{pmatrix}=\begin{pmatrix}C_1 & C_2\end{pmatrix}$, $\tau=\begin{pmatrix}X_1\\ X_2\end{pmatrix}$, then according to the Cramer rule, the solution of the equation is as follows.

$$\alpha_1=\frac{\det(\tau \quad C_2)}{\det(C_1 \quad C_2)} \qquad (13)$$

$$\alpha_2=\frac{\det(C_1 \quad \tau)}{\det(C_1 \quad C_2)} \qquad (14)$$

So we find the α_1 and α_2 with eligible.

According to the above algorithm, carries on the simulation test, in a remote sensing image as an example, the extraction algorithm of construction characteristics point cloud based on cultural surface for the construction of a point cloud, the results are as follows:

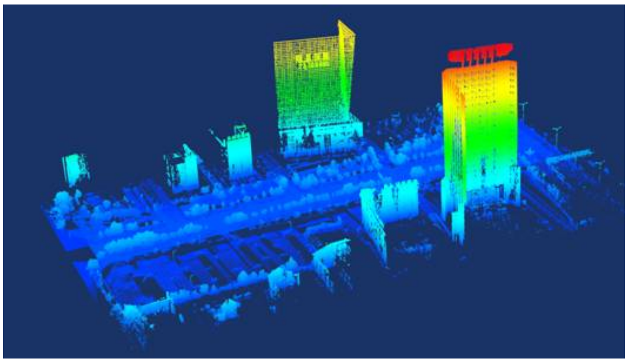

Figure 2. Point cloud architectural feature extraction results

It is seen from the result, the extraction result can be very good expression for the buildings, is conducive to the structure of the 3D reconstruction.

Point cloud matching of RANSAC algorithm based on the affine invariant optimized
Geometric transformation of point cloud data

According to cultural curve feature extraction to get point cloud data sets, make sure the feature points of two point cloud data sets with registration, use these feature points and a point cloud data sets for reference, to solve the parameters of geometric transformation matrix R between the two point cloud data sets, another point cloud data sets is normalized to the standard coordinate system with the reference point cloud data sets.

A given projection transformation between two point cloud data sets as follows:

$$\begin{bmatrix}x_i'\\ y_i'\\ 1\end{bmatrix}=\begin{bmatrix}r_0 & r_3 & r_6\\ r_1 & r_4 & r_7\\ r_2 & r_5 & r_8\end{bmatrix}\begin{bmatrix}x_i\\ y_i\\ 1\end{bmatrix} \qquad (15)$$

In the equation, (x_i', y_i') is the pionts of reference point cloud data sets, (x_i, y_i) is the points corresponding to (x_i', y_i') on target point cloud data sets. Here called the transformation matrix as R, R has eight degrees of freedom, the theory of choice at least 4 diagonal points can estimate the R [7].By equation (15) we can get equation (16).

$$\begin{cases} x_i' = \dfrac{r_0 x_i + r_3 y_i + r_6}{r_2 x_i + r_5 y_i + r_8} \\ y_i' = \dfrac{r_1 x_i + r_4 y_i + r_7}{r_2 x_i + r_5 y_i + r_8} \end{cases} \quad (16)$$

Get 4 eight independent linear equations from diagonal points, and get the R through solution of equations, so we put the points on the target point cloud data sets one-to-one correspondence to normalize to the reference point cloud data sets in the coordinate system.

Made a preliminary normalized cross-correlation matching, there are a lot of false matching points, at this time use RANSAC algorithm to eliminate false matching points, estimate the transformation matrix.

RANSAC make full use of all the initial matching points, according to a permissible error can make all match be divided into inside and outside, taking advantage of the accurate characteristics of interior point data for parameter estimation, thus the inaccurate matching points are exclud. The specific steps of homography matrix estimated by RANSAC are as follows:

First of all, the current best estimate interior point number T_i is set to 0.

1) Repeated N times of random sampling. Matrix R matching point estimate need 4 pairs, to determine a proper sampling number N, to ensure that the sample of 4 pairs matching points are within a high enough probability. P is represent to the probability, commonly takes 95%. Set P_i as the probability to any a pair of matching points is interior point, $\omega = 1 - P_i$ is the probability of any matching points for outside. So the sampling to N times are: $(1 - P_i^4)^N = 1 - P$, then $N = \dfrac{\log(1-P)}{\log(1-(1-\omega)^4)}$.

2) According to 4 pairs matching points to calculate the transformation matrix R;

3) Calculate each match point after matrix transformation to the corresponding matching point Euclidean distance $l(x_i', Rx_i)$;

4) Set a threshold value G, the matching point meet $l < G$ as the interior point;

5) Comparing the current interior points number with T_i, if it is greater, then R and the current point set as the current best estimate, update T_i; if it is equal, then select the lower registration as the current best estimate. The remaining required number of iterations of dynamic estimate is N at the same time, if the current number of iterations to R, then retained the current interior point set and stop the iteration;

6) All of the matching point in the current point set reestimate R by the DLT algorithm.

The speed optimization of RANSAC algorithm

Affine invariant is used to restrain the sample which extracted by RANSAC algorithm, can effectively reduce the amount of sample, so that can accelerate the rate of RANSAC registration algorithm.

Assume that, the proportion of the overlap between the source data set S and target data set T is ω in data set. In order to convenient, overlap ratio estimation is directly given. In Euclidean distance, compute the length $l_{\max}$ between two points data which are the furthest data points, which can draw coplane four-point constraints of the length of the distance between the point:

$$d_\omega = l_{\max} \cdot \omega \quad (17)$$

Randomly select a points S_1 in the source data set S, and randomly look for another S_2, to get equation (19):

$$d_\omega - \sigma \le \|S_2 - S_1\|_2 \le d_\omega + \sigma \quad (19)$$

And meet equation (20) at same time.

$$\min(\|\overline{S_2S_3}, \overline{S_2S_1}\|_2) \quad (20)$$

This means that makes the distance length meet the constraint conditions at the same time, $\overline{S_2S_3}$ and $\overline{S_2S_1}$ should as far as possible between the vertical.

Through the former three points, we compute the vector:

$$\overline{S_2S_3} + \overline{S_2S_1} = (S_1 - S_2) + (S_3 - S_2) \quad (21)$$

From this we can get point S':

$$S' = S_2 + \overline{S_2S_3} + \overline{S_2S_1} \quad (22)$$

And find the point S_4 close to S' in source data set S, and meet the equation (23).

$$\min\left(\left\|\overline{S_2S_4}\cdot(\overline{S_2S_3}\times\overline{S_2S_1})\right\|_2\right) \quad (23)$$

This condition makes the points S_4 is in the same plane with $\{S_1,S_2,S_3,S_4\}$ as much as possible.

Through the above way, can choose four coplanar $\{S_1,S_2,S_3,S_4\}$, so affine invariants is formed between them as follows:

$$r_1=\frac{\left\|\overline{eS_3}\right\|_2}{\left\|\overline{S_1S_3}\right\|_2} \quad (24)$$

$$r_2=\frac{\left\|\overline{eS_4}\right\|_2}{\left\|\overline{S_2S_4}\right\|_2} \quad (25)$$

To do so is to constrain the shape of quadrilateral as square as possible, and to avoid quadrilateral uneven length, which can lead to enlarge error and affect the match result. Although we want to constrain quadrilateral for the square, but the actual cases can't completely appears as a square, so point e isn't midpoint, invariants r_1 and r_2 not completely equal, for consistent coplanar won't impact for four sets.

In addition, this method needs only two points on repeat random, to find the right points S_2 and S_3 to meet the conditions, and therefore the complexity of the selection is $O(n^2)$.

Know according to the previous analysis, can make use of iterative selection consistent coplane four-point, do estimate for Euclidean transform H_c, and choose the estimate transformation H with the best degree of consistency between the source set S and target set T and under the estimated transformation.

Under the estimated transformation H_c, the degree of consistency between source data S and target data set T, using meet under the certain error threshold δ, consistent point number is for measuring.

Besides, also constraint corresponding points in the direction of the surface, make them within a certain range of deviation. Assume that the source one point as $S_i \in S$, the corresponding points in the target is $T_i \in T$, a constrained by the following equation:

$$\left\|T_i - H_c\cdot S_i\right\|_2 \le \delta \quad (26)$$

$$\frac{n_{T_i}\cdot n_{H_c\cdot S_i}}{\left\|n_{T_i}\right\|_2\left\|n_{H_c\cdot S_i}\right\|_2} \ge \cos\theta_\delta \quad (27)$$

In the equation, n is the normal vector of the point, and θ_δ is the error threshold of the point of view.

The simulation of algorithm

To verify the effectiveness of the proposed improved algorithm, simulation experiments on it. Taking a residential area as an example, based on the GIS images, the proposed 3D modeling algorithm based on the culture surface model and the improved RANSAC algorithm for the construction of 3D reconstruction. The result is shown as follows

Figure 3. GIS remote sensing images of residential area

Figure 4. 3D modeling diagram of residential area

Then, the improved RANSAC algorithm of speed in the simulation, the results are as follows:

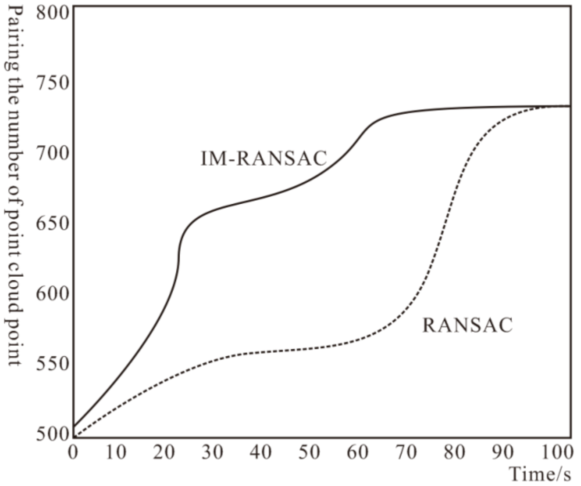

Figure 5. Computation speed simulation of improved RANSAC algorithm

Conclusion

Seen from the simulation results, that the proposed 3D modeling algorithm based on the culture surface model and the improved RANSAC algorithm has better performance of 3D modeling, and the computing speed of the improved RANSAC algorithm is better than the original algorithm.

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