Simulation of Coastlines Based on Cloud Fractal

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Abstract. It is a very important subject to simulate coastlines based on fractal method. In order to describe the coastlines realistically, we should consider the uncertainty, e.g. fuzziness, randomness and other uncertainties. Based on cloud model theory, the paper puts forward an improved fractal method of midpoint subdivision interpolation, which uses cloud model to express the randomness contained in the self-similarity of natural scenery, and embodies the diversities of uncertainty. The experiments of simulation of coastlines validate the proposed improved method.

Keywords: coastline simulation, fractal, cloud model, uncertainty

1. Introduction

Coastline analysis is an important application domain of fractal theory. Mandelbrot proposed the concepts of fractal and fractal dimension In 1967[1]; Goodchild validated the results of fractal dimension calculation for Mandelbrot In 1980[2]; Phillips, Qiu, Andrele, Paar et al. researched the characteristics of fractal dimension [3-7]; Zhu and others revealed the fractal nature of Jiangsu tidal flat line, and studied fractal calibration of the length of the coastline of Jiangsu Province In 2000[8]. Based on box-counting method with GIS in the map of the same scale, Zhu and others calculated and compared the fractal dimension characteristics of coastlines of China, United States, Australia, and explored their possible change of the fractal characteristics with the latitude in 2001[9]; In the same year, the author and others used random midpoint subdivision interpolation to simulate the coastline of Jiangsu Province, and explored the dynamic change of temporal series of coastline[10]; Taking the coastline simulation of Jiangsu Province as an example based on GIS, Lu and others used the midpoint subdivision interpolation method to simulate the coastline and calculated the value of the fractal dimension in 2002[11]; In the same year, the author used the midpoint subdivision interpolation method and the Koch curve method to explore coastline simulation. Based on GIS, they put emphasis on the method of Koch curve and introduced its principle and process to simulate coastlines[12]. In general, the fractal research of coastline is just the calculation of coastline’s fractal dimension. So far, the fractal simulation is at a beginning step yet[10]. Therefore, the coastline fractal simulation needs further development.

At present, because of many uncertainties, there is much randomness in the simulation of coastline, this has been considered in coastline simulation algorithm, so a number of random factors have been acceded to the algorithms. However, these algorithms generally do not meet the requirements of fractal simulation, have yet to be further improved.

Cloud is a model described by linguistic values for representation of uncertain relationships between a specific qualitative concept and its quantitative expression. It is introduced to reflect the uncertainties of the concepts in natural languages. Cloud integrates the concept of randomness and fuzziness. The normal random number generation method in normal cloud generator algorithm overcomes the insufficiency of common method to generate random numbers. It can produce random numbers which can be predictable and replicated, and this random numbers present to be a random sequence as a whole, but do not show any

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obvious pattern, so it can meet the requirements of fractal simulation, thus combining cloud model and fractal to simulate nature is feasible \cite{14}. This paper takes the coastline simulation as an example to explore the feasibility of the combination of cloud model and fractal, and analyzes the uncertainty of the cloud fractal methods embodied in natural simulation. We adopt the secondary development method with Visual Basic and ArcGIS Engine and do the experiment of cloud fractal coastline simulation based on GIS, the results show that the method is effective.

2. Random Midpoint Subdivision Interpolation Algorithm

Random midpoint subdivision interpolation method is the basic technology that describes the characteristics of natural fractal \cite{15}; it is a technique that N. Wiener used to study Brownian motion in 1920. The main steps of Random midpoint subdivision interpolation Algorithm are as follows:

1) Given the current interval \([y_1, y_2]\), and divide it into two halves, as shown in Fig. 1.

![Random midpoint subdivision interpolation](image)

Fig. 1 : Radom midpoint subdivision interpolation

2) Use formula: \( y = \frac{1}{2}(y_1 + y_2) + N(0,s) = \frac{1}{2}(y_1 + y_2) + sN(0,1) \)

Calculate the centre value \( y \), here \( N(0,s) \) is a Gauss random variable whose Mean is 0, standard deviation is \( s \).

3) In the new interval, repeat the above process, reduce the standard deviation of the new interval to its \( \frac{1}{2} \)

The algorithm for calculating the interpolation position is as follows:

For a given initial line segment AB, it means that the two control points are A and B. Firstly move a distance Roughness in the direction of perpendicular bisector in the position of mid-point of AB randomly, then connect the control points and the interpolation points. The moving directions are controlled by the parameter sign, if sign =1, the midpoint move left with the distance of Roughness. If sign = -1, the midpoint move right distance with the same distance. Finally connect the control points and the interpolation points to form a curve. The values of sign change alternately. Continuously subdivide each line segment, iterative times are controlled by the parameter Times. Interpolation points are as following formula:

\[
X_{mid} = \frac{X_i + X_{i+1}}{2} + \text{sign} \times \text{Rnd()} \times \text{Roughness}
\]

\[
Y_{mid} = \frac{Y_i + Y_{i+1}}{2} + \text{sign} \times \text{Rnd()} \times \text{Roughness}
\]

In the formula, Sign is the direction control parameter. Roughness is the displacement control parameter. If Roughness is small, the curve is gentle, and has little wave. If it is large, the curve has bigger wave. In the actual simulation process, Roughness values and the distance between two points can be linked, Roughness can be regulated also, the value of Roughness controls the bending degree of curve, and it can be called “Roughness” parameter. Here take the method of random midpoint subdivision interpolation, after each Roughness subdivision, it will be reduced to its half. Rnd () can provide random variables between \((0, 1)\) \cite{16}.
3. The Simulation of Coastline Based on Cloud Fractal

3.1. The Method of Cloud Fractal
The self-similarity is the basic nature of the fractal, and it supplies a theoretical basis for the computer simulation of fractal graphs. In nature, among the nonlinear complex phenomena there exists some self-similar or scale-free features, which are simple but important. Using fractal theory to depict those nature scenery is feasible, because it can recur the original object through only a small amount of information, and it has many good features: less specific information, easiness and high accuracy [17]. However, the natural objects are not strictly self-similar. Their self-similarity in the statistics is proved true, and the structure of self-similar "level" is limited. Therefore, in the fractal simulation algorithm, we can add a random value within a certain scope to each parameter which controls fractal to reflect the randomness. Therefore, in order to achieve a more realistic simulation of nature, how to produce random number to meet the requirements of fractal simulation is one of the key factors of the fractal process [13].

Cloud model is a transformation model with uncertainty between the quality concepts and their quantity expression. It uses three digital characteristics $Ex$, $En$, $He$ to express quality concepts. Where $Ex$ represents the expectation of cloud drops in the domain; $En$ is the uncertainty measurement of quality concept, it is defined by both the fuzziness and randomness of concept; $He$ is the uncertainty measurement of entropy, namely the entropy of entropy. It reflects the agglomeration of all points representing the concept in the data domain [14]. Because in natural science and social science, there are many examples of obtaining normal distribution, Deyi Li and others constructed normal cloud model, and proved the pervasiveness of normal cloud model [19]. Cloud model has been successfully applied to the fields of intelligent control, data mining, knowledge expression, and image segmentation.

Deyi Li, etc. with the help of the extended cloud generator and simple function iteration, simulated the fractal growth of natural tree. Research shows that the fractal-based simulation method can be more effective and more realistic to simulate the uncertainty of natural phenomena, and to express the intercommunity of natural phenomena hidden under the surface difference, and it has an important research value and broad application prospects. Integrating cloud model and fractal further reveals the randomness included in the self-similarity of complex events, demonstrating the diversity of uncertainty, and the expectation of the extended cloud reflects the regularity hidden in the uncertain phenomenon [14]. In this paper fractal cloud will be applied to the simulation of the coastline. Based on cloud model, using fractal to simulate coastline, we are exploring whether the method is feasible and effective.

3.2. The Simulation of Coastline Based on Cloud Model
In the random midpoint subdivision interpolation algorithm, the bending degree of the coastlines is closely related to the Roughness degree. When the Roughness is small, the curve is gentle, and has little change. If it is large, the curve has bigger wave, and change increases [10]. Nevertheless, the actual results of the simulation has little change when the parameter Roughness changes. The reason, mainly in the random midpoint subdivision interpolation algorithm the change rule of Roughness lacks of randomness. In each subdivision, Roughness will be reduced to its half then the function of rnd() is very small.

To solve the issue above and to simulate the coastline, the paper introduces cloud model into the method of midpoint subdivision interpolation, and uses the method to simulate the coastline. It uses normal cloud model generator to produce random values which in a range accords with normal distribution. And uses the produced cloud drops to control the values of Roughness between every two neighbor control points, then change the bending degree in different sections, and calculate the distance between the neighbor points, and calculate the average distance value $d$ of all points. For every two neighbor control points, calculate their distance $CtlDis$. If the value of $CtlDis$ is smaller than $d$, take the half of the original value of Roughness as the new expectation value in the iterative process, and produce a new value of Roughness’ based on normal cloud generator, otherwise, take the half of the original value of Roughness as the new value of Roughness’ in next iteration [16].

3.3. Experimental Analysis and Discussion
Based on Visual Basic and ArcGIS Engine, with the support of GIS technology, we design and develop the
program for coastline simulation based on cloud fractal, by calling Matlab console to implement normal cloud generator, and to gain random Roughness values. By clicking of the mouse, we can select a certain number of control points to approach the target through the program to realize the coastline cloud fractal simulation. We use the data of Shandong, Guangdong coast from the Chinese borders 1:4 million vector data (shp format), dealt by ArcGIS in the experiment. Respectively, using the traditional midpoint subdivision interpolation method and cloud fractal interpolation method to simulate the coastline of Shandong Province and Guangdong Province, and comparative analysis of the experimental results are in Fig. 2 and Fig. 3.

Fig 2: the simulation of Guangdong coastline (a) random midpoint subdivision interpolation; (b) cloud fractal

Fig 3: the simulation of Shandong coastline (a) random midpoint subdivision interpolation; (b) cloud fractal

because we are not sure whether there is certain restriction among Roughness, the number of iterations, the number and location of the control points and so on, and how to make the best combination of them has not a very clear standard [16]. We have to do many experiments for this paper, in every experiment we observe the following principles: When the effects of traditional random midpoint subdivision interpolation method are relatively good, under the same conditions, with the same control points, we use cloud fractal method to do the experiment. At last two groups of comparative results are got above, we can see the results from cloud fractal simulation system present more randomness and be more realistic than the results of random midpoint subdivision interpolation experimental system. Through experiments we find that the more complex curve, the results of cloud fractal simulation are much better, for the simple curve, the comparative results are not obvious.

It should be pointed out: In this paper, we use the visual judgement method to analyze experimental results, quantitative evaluation methods have not been used, and this is our target of next research. Based on the past experience, because of the complexity and irregular characteristic of nature, any simulation can only be established under certain conditions, within certain limits, if any simulation results are amplified, we will find the difference between the micro-structure is great [11]. Therefore, how can be more accurately, more realistically to simulate the coastline, it’s many Fractal researchers’ goal for long, in this paper we have done a few of attempts, and we have to do more in the future.

4. Summary

Integrating cloud model and fractal, we get cloud fractal model, and extended cloud is realized in it. Cloud model has the advantage to analyze fuzziness and randomness synthetically and fractal theory has the advantage to analyze phenomenon of self-similar and scale-free, the combination of the two methods is an effective way to analyze uncertainty problem. In this paper the cloud fractal has been applied to shoreline
simulation, comparing the simulation results of cloud fractal with the simulation results of random midpoint subdivision interpolation; it shows that this cloud fractal method is effective. How to do quantitative analysis of fractal simulation results and achieve the automatic calculation of the length of the coastline based on the method are our further goals in the direction.

5. Acknowledgements

This paper is supported by National Key Basic Research and Development Program: 973 Program (2006CB701305), and by the Fund of the State Key Laboratory of Resources and Environmental Information System (A0682).

6. References


