2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)
June 28 - July 1, 2017 at Maison Glad Jeju, Jeju, Korea

Haptic Texture Rendering Using Random Fractal Surface

Seongwon Cho[1], Sunghwan Shin[2] and Seungmoon Choi[3]
[1,2,3] Department of Computer Science, POSTECH, Pohang, 37673, Korea
(Tel : +82-54-279-5661; E-mail: kardy04@postech.ac.kr, scaut11@postech.ac.kr)
(Tel : +82-54-279-2384; E-mail: choism@postech.ac.kr)

Abstract – In this paper, we presented a haptic texture modeling and rendering method using random fractal surface. Fractal is an effective way to render irregular surface in computer graphics, and it can be also effective for haptic texture rendering of irregular surfaces. Also, surface characteristics can be easily changed by setting parameter values of the fractal algorithm. We generated several random fractal surfaces and rendered them using force feedback device. As a result, the parameter value of fractal generation algorithm seems to be related to the perceptual characteristics like roughness and stickiness.

Keywords – Haptics, Texture, Fractal, Rendering.

1. Introduction

In haptics, modeling and rendering irregular texture is one of the challenging problems. Many previously presented methods assumed the regular or probabilistic distribution of texture. To handle irregular textures efficiently, we adopted a fractal structure in haptic texture. In computer graphics, the fractal is used to render irregular surface or natural scene which can't be rendered by Euclidean geometry [1]. We thought fractal also can be useful for haptic rendering to render irregular surface. Also using fractal has the advantage to generate different surfaces to change only parameter values. About this, Costa and Cutkosky had researched roughness perception with fractal [2]. Previously rectangular groove or predefined artificial surface are used to render haptic texture, and stochastic method is also used [2].

2. Method

2.1 Random Fractal Generation Algorithm

Many different algorithms have been developed to generate random fractal surfaces [3]. Among them, we used the midpoint displacement method to generate fractal surfaces because of its recursiveness and easiness. In a recursive fractal algorithm, we can set the detail of surface easily by changing the iteration level because an output of the previous iteration is used as an input of current iteration. The easiness of the algorithm increases the usability of the fractal texture modeling algorithm.

The input of this algorithm is a square-shaped surface, characterized by four corner vertices. For every single iteration, the algorithm divides the given surface into four new sub-squares, whose self-similarity is $1/\sqrt{2}$ through interpolation and addition.

Figure 1 shows the overall process of the midpoint displacement method. The heights of initial four points are set by Gaussian random number. Height of center point of square z_{center} is calculated as

$$z_{center} = average(z1, z2, z3, z4) + delta \quad (1)$$

where $z1, z2, z3, z4$ are the heights of four corner vertices and $delta$ is $\sigma^2 r^{2Hn} = \sigma^2 (\frac{1}{2})^{nH}$ for random addition. σ and H values affect properties of the surface. After that, heights of mid-points of each line z_{edge} is calculated by

$$z_{edge} = average(z5, z6, z_{center}) + delta \quad (2)$$

where $z5, z6$ are the heights of two adjacent vertices for each edge.

Finally, the height of the center point is updated with 4 mid-points of each line by Eq. (1). One iteration consists of these 3 steps. Generation of the random fractal surface is calculated by repeating this cycle for level-times.

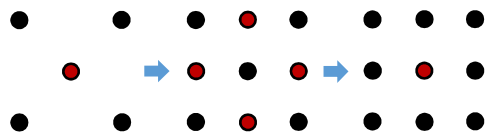


Fig. 1. The process of 2D midpoint displacement algorithm.

2.2 Analysis of Fractal Surface

Different parameter values in generating fractal surface give different textured surface, which would give a different feeling to the user. However, these parameters are not explicitly matched to the characteristics of the textured surface. To handle this problem, we adopted the analyzing methods used to quantify and characterize the fractal surfaces objectively.

Among many candidates, we chose FSHOT method which characterizes roughness and anisotropy of surface in all direction. This method is commonly used for calculating fractal signatures accurately to characterize surface profiles when the surface image is based on random fractal [4]. Also, the roughness and anisotropy values calculated from the method are frequently used metrics to describe the haptic texture.

Originally, the FSHOT method uses pixel's grayscale value of the surface image. However, since our fractal surfaces have the height information instead of brightness information for each vertex, we use height data instead of gray-scale value. Also, the height value is highly correlated to the brightness value in analyzing the surfaces.

In the method, the surface is scanned by a ring-shaped moving window. For each center point of the window, every possible pair of two points in the window should be analyzed. However, to simplify the calculation and to remove the ambiguity of angles between two points, we fixed the one point in the pair to be a center point.

For each pair, we calculate the direction, distance, and absolute difference of height between two points. The direction is the angle between two points, and it is rounded by 2 degrees to make enough data for each direction. About same direction and same distance, it saves only maximum absolute difference between them.

After calculating, we can categorize the data points by the direction. For each direction, a log-log plot of distance and absolute differences would be fitted into a line if the surface is based on the fractal Brownian motion [4]. The slope of the fitted line is Hurst coefficient of that direction. Hurst coefficient is a value to determine fractal dimension. Fractal dimension is calculated as FD = 3 – H.

The distribution of the Hurst coefficient values for different directions on polar coordinate will be gathered into an ellipse. The parameters of fitted ellipse's profile can be used to express the characteristics of the surface. The characteristic values are summarized in Table 1.

Table 1. The Characterizing signatures of fractal surface

Signature	Equation	Explanation
Sta	$^{a}/_{2}$	Hurst coefficient of roughness part
Str	$^{a}/_{b}$	Anisotropy of surface
FS_H	$3-\frac{ab}{\sqrt{(a\sin\theta)^2+(b\cos\theta)^2}}$	Horizontal directions' FD
FS_V	$3-\frac{ab}{\sqrt{(a\cos\theta^2+(b\sin\theta))^2}}$	Vertical directions' FD

(* Minor axis a, major axis b, rotation angle θ)

3. Result

3.1 Generating Fractal surface

We generated several random fractal surfaces by changing H parameter value 0.90 to 0.30 with fixed sigma and iteration level, and then analyzed these surfaces with FSHOT method. The analyzed result in Table 1 shows that the decreasing of H value induces decreasing of Sta, while fractal dimension FD_{Sta} monotonically increases. We can adjust the roughness of the generated textured surface using H parameter. Figure 2 shows the results of generating surfaces by different H. Table 2 shows the result of fractal signatures of the surfaces.

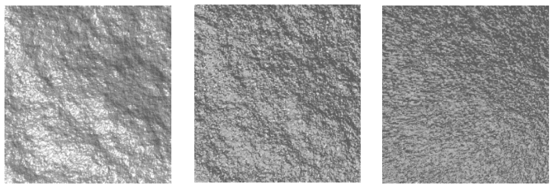
Table 2. Surface signatures by H values

H	Sta	FD_{Sta}	S_{tr}
0.90	0.6478	2.3522	0.8630
0.75	0.5937	2.4063	0.8579
0.60	0.5211	2.4789	0.8975
0.45	0.3966	2.6034	0.8534
0.30	0.3238	2.6762	0.8566

3.2 Haptic Rendering

After generating fractal surfaces, we rendered them to see the effect of H on the perceptual characteristic of haptic texture. We used the Novint falcon device for force-feedback, and the Chai3D library was used to implement the rendering program.

Many haptic texture algorithms have been proposed to render haptic texture when the height map is given. In this work, we used the textured-normal based method. The force is rendered only when the haptic interaction point(HIP) is below the textured surface in the z-direction. The direction of the force was determined by connecting the current HIP position and the closest point on the surface to it, and the magnitude was calculated by multiplying the penetration depth to the stiffness of the surface. As a result, surfaces with different H values made perceptually different haptic textures, and it seems that changing H values changes the perceptual roughness and stickiness simultaneously.



(a) H = 0.9 (b) H = 0.6 (c) H = 0.3

Fig. 2. Result of generated fractal surfaces.

4. Conclusion & Future Work

In this paper, we used a randomly generated fractal surface as a height map of the haptic textured surface. The generated surfaces were easily characterized by some fractal parameters, which seems to be highly related to the perceptual characteristic of the textured surface (e.g., roughness, bumpiness, stickiness).

In the next step, we plan to conduct a user study to find the relation between the perceptual space of the texture and the fractal parameters. By unveil the mapping between them, we expect to propose a haptic texture design guideline for the desired perception.

Also, we need to find the way to express the real textured surface as a random fractal surface. We will analyze real surface images by using FSHOT method, and we will select surfaces that show similar results to random fractal surfaces. After that, we will express those textures.

Although the accuracy of the detailed modeling would be lower than data-driven method, this method can be a better option in mobile computing environment considering its short time of modeling and handiness.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2017R1A2B4008144) and Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government

(MSIP) (No.2017-0-00179, HD Haptic Technology for Hyper Reality Contents)

References

[1] M. Rahnemoonfar et al., "Fractal and surface modeling," in *International Society for Photogrammetry and Remote Sensing*, 2004.
[2] M. Costa and M. Cutkosky, “Roughness Perception of Haptically Displayed Fractal Surfaces,” *Proc. ASME Dynamic Systems and Control Division*, vol. 69, no. 2, 2000, pp.1073-1079
[3] D. Saupe, “Algorithms for random fractals,” in *The Science of Fractal Images*. New York: Springer, 1988, pp. 71-136.
[4] P. Podsiadlo and G. W. Stachowiak, “Directional Multiscale Analysis and Optimization for Surface Texture,” *Tribol Lett*, vol. 49, pp. 179-191, Jan. 2013.