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Perceived Directionality of Random-phase Fractal Surfaces Based on Mojette Transform

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ABSTRACT
Based on a set of experiments, this paper investigates the relationship between perceived directionality of surface textures and features from Mojette Transform. It was found that two properties of Mojette Transform (the variance and the local maximum of projection vectors) are related to human perception on directionality. Based on these features, a measurement model was proposed for perceived directionality.

Keywords
Mojette transform , perceived directionality, random-phase.

1. INTRODUCTION
Directionality is known to be an important dimension in texture perception and visual texture classification. Many direc- tion measurement methods have been proposed [1][2]. In [3], surface height maps were rendered and animated in real-time with controlled illumination. The surfaces were from a random phase noise with magnitude spectrum as in Equation 1.

$$M(f,\theta)=(1/f^{\beta})\left(e^{-(\theta-\theta_0)^2/2\sigma^2}\right)\left(\frac{\delta}{\delta_n}\right) \qquad (1)$$

where: $M(f,\theta)$ is the polar representation of magnitude spectrum, and where f is radial frequency and θ is angular frequency; θ_0 is dominant angular frequency and δ_n is RMS Roughness normali zation factor; β is the roll-off factor; δ *is the RMS roughness and* σ^2 is the angular variance.

Observers' judgments of the directionality of surfaces were obtained by direct-ratio estimation, and either the method of pair-wise comparisons or the method of constant stimuli. The responses were used to derive a perceptual scale of directionality (perceived directionality) that could be related to physical properties of surfaces.

It was found that four parameters of the magnitude spectrum of such surfaces significantly affect human perception of directionality, i.e. angular variance (σ^2), RMS roughness(δ), central radial frequency (f_c) and bandwidth (B_w) [3](see Equation 2 and 3).

$$f_c=(f_h+f_l)/2 \qquad (2)$$

$$B_w=f_h-f_l \qquad (3)$$

where f_h and f_l are, respectively, the upper cut-off frequency and lower cut-off frequency of the Butterworth band-pass filter.

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Radon Transform has been effectively used for texture direction detection and classification [2]. Since the image spectrum can be determined by the surface spectrum given an illumination direction, by the Projection Slice Theorem the Radon transform of the image is related to the surface spectrum. As a discrete form of Radon transform defined for specific projection angles [4], the Mojette transform has advantage over traditional Radon Transform in texture direction detection. The goal of this study is to investigate how features extracted from Mojette Transform are related to perceived directionality of surfaces defined using (1). In the Mojette Transform, each component of a projection angle is the sum of all the pixels crossed by the appropriate projection line. For each projection angle, all component values are used to calculate a normalized variance. Same as in [4], Nproj =72 projection angles were used with angles ranged from to in a step of 2.5°. This means that a Nproj - dimension column vector is derived from each image.

Projection vectors V_s can capture the directional information of surface textures generated using Equation 1 with different σ2, δ, f_c and B_w (see Equation 3 and 4). This paper proposes a measurement model of perceived directionality, which corresponds to human's perception of directionality of random-phase fractal noise surfaces.

2. EXPERIMENTS
We investigated how the variance M_v and the local maximum M_p are related to the perceived directionality. The variance here is the square of the standard deviation.

The experiment contains two parts. Surfaces and corresponding perceived directionality obtained from [3] were used in our experiment.

2.1 How Mv and Mp are related to perceived directionalities corresponding to different σ2 and δ
As described in [3], σ^2 and δ separately have significant effects on perceived directionality: increasing σ decreases perceived directionality; while increasing δ increases perceived directionality. Moreover, σ^2 and δ have significant effects on perceived directionality when both were varied in the same experiment: the effect of σ^2 was larger than that of δ.

In this section, experiment contains three parts: 2-A, 2-B, 2- C. These surfaces were all generated by Equation 1.In 2-A, the surfaces had five different values of σ2 (20.0, 51.48, 132.5, 341.03 and 877.8 degree squared); the correlation was observed at four levels of δ (0.012, 0.016, 0.02 and 0.024 cm). No comparison was made between surfaces having different δ (Figure 1). In 2-B, the surfaces were sampled at five values of δ (0.012, 0.016, 0.02, 0.024 and 0.028cm); surfaces with these values of δ were obtained at four levels of σ2 (20.0, 51.48, 132.5 and 341.03 degree squared). The surfaces only having different δ and constant σ^2 were compared (Figure 2). In 2-C, the surfaces were sampled at five different values of σ2 (20.0, 51.48, 132.5 and 341.03 degree squared) and four different values of δ(0.012, 0.016, 0.02 and 0.024 cm). Then the variance M_v and the local maximum of M_p of projection vectors V_s will be computed by analyzing surfaces in each experiment. Both the variance M_v and the local maximum of M_p of projection vectors V_s were plotted against perceived directionality (Figure 3 and Figure 4). The results will be discussed in section 3.

2.2 How M_v and M_p are related to perceived directionalities corresponding to different f_c and B_w

As we know from [3] that f_c and B_w separately have significant effects on perception of directionality: increasing f_c increases perceived directionality; increasing B_w increases perceived directionality. When the combined effects of fc and B_w were observed, the perception of directionality was significantly affected by only f_c.

In this section, experiment contains three parts: 2-D, 2-E, 2-F. These surfaces were all generated by Equation 4;

$$M(f,\theta)=\left(\frac{\delta}{\delta_n}\right)(1/f^{\beta})\sqrt{\frac{1}{1+\left(\left(\frac{1}{f_h-f_l}\right)\left(\frac{(f_h f_l-f^2)}{f}\right)\right)^2}}\left(e^{-(\theta-\theta_0)^2/2\sigma^2}\right) \quad (4)$$

In 2-D, the surfaces were sampled at four values of fc (2.81, 4.22, 5.63 and 7.03 cpd) and constant B_w. The correlation was observed at three constant levels of B_w (0.94, 1.88 and 2.81 cpd). No comparison was made between surfaces having different bandwidths (Figure 5). In 2-E, four different values of B_w (0.47, 1.88, 3.28 and 4.69 cpd) were used. Three constant levels of fc (2.81, 4.69 and 6.56 cpd) were chosen. No comparison was made between surfaces having different f_c (Figure 6). In 2-F, a total of sixteen surfaces were generated with four different values of fc (2.58, 4.22, 5.86 and 7.5 cpd) and four different values of B_w (0.47, 1.88, 3.28 and 4.69 cpd) (Figure 7 and Figure 8). The results of experiment will be discussed in section 3.

3. RESULTS

Regarding the relationship between M_v, M_p and perceived directionality, the following was observed:

- Perceived directionality correlates to M_v and M_p with regard to changing σ^2, fc and B_w; all coefficients of determination (R^2) are significant at $p<0.01$ level. (see Table 1)

- The changing trends of both Mv and Mp are consistent with that of B_w .(see Figure 6 and Figure 8)

- The changing trends of M_v and are related to that of σ^2. While decreasing σ^2 increases perceived directionality, M_v and Mp also increase. (see Figure 1 and Figure 3)

- The changing trends of M_v and M_p are related to that of fc. While increasing fc increases perceived directionality, M_v and M_p decrease.(see Figure 5 and Figure 7)

- The changing trends of M_v and M_p do not well coincide with δ. (see Figure 2 and Figure 4)

A multi-linear regression model was used to define a measurement model of perceived directionality (ρ_{fit}) corresponding to different σ^2, which best captures the perceived data:

$$\rho_{fit} = C + aM_v + bM_p \quad (5)$$

The model parameters were obtained from multi-linear regression as:

$$\rho_{fit} = -0.4761 - 1166.086 M_v + 51.8748 M_p \quad (6)$$

p is less than 0.01 and R^2 =0.9910 (Table 1).

$$\rho_{fit} = 69.1161 - 314390.8 M_v - 757.3907 M_p \quad (7)$$

p is less than 0.01 and R^2=0.8087(Table 1).

4. CONCLUSIONS

In this paper, the relationship between chosen computational features and human's perceived directionality was studied based on a set of experiments. The experimental results demonstrate that the variance and the local maximum of Mojette projection vectors can better capture the variance of human's perceived directionality induced by angular variance and central radial frequency. However, although the RMS roughness also has an effect on perceived directionality, the Mojette features we used are not good enough to capture these variations.

Future work may further investigate relationship between other directional texture features, e.g. phase congruency, and perceived directionality.

5. REFERENCES

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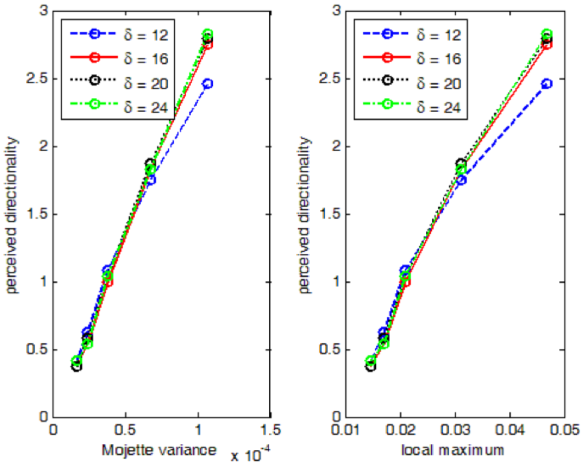

Fig 1. 2-A:different σ^2 and same δ

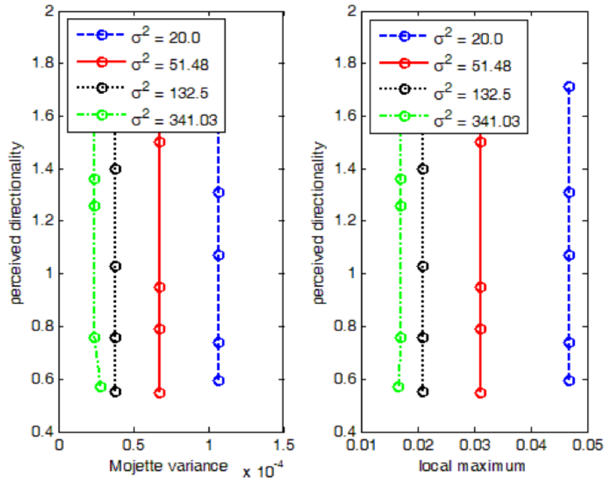

Fig 2. 2-B: different δ and same σ^2

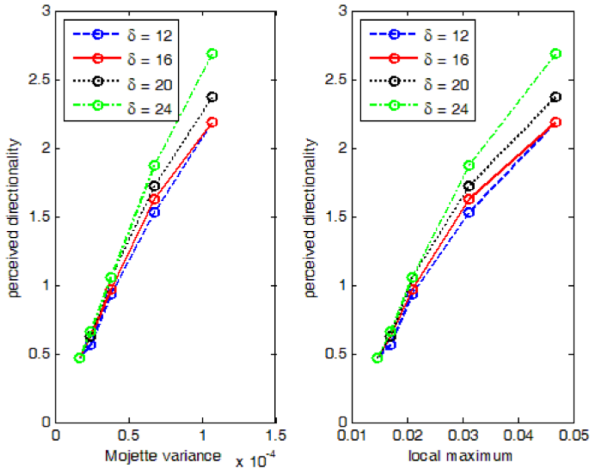

Fig 3. 2-C:different σ^2 and different δ

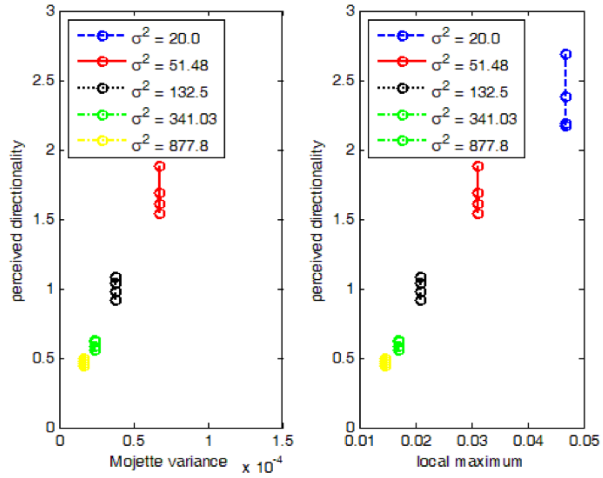

Fig 4. 2-C:different σ^2 and different δ

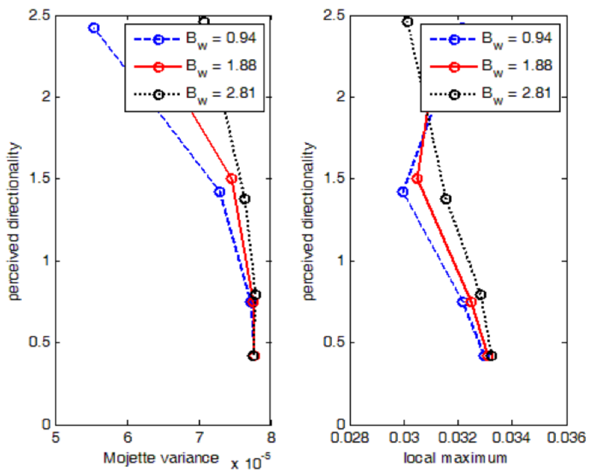

Fig 5. 2-D:different f_C and same B_W

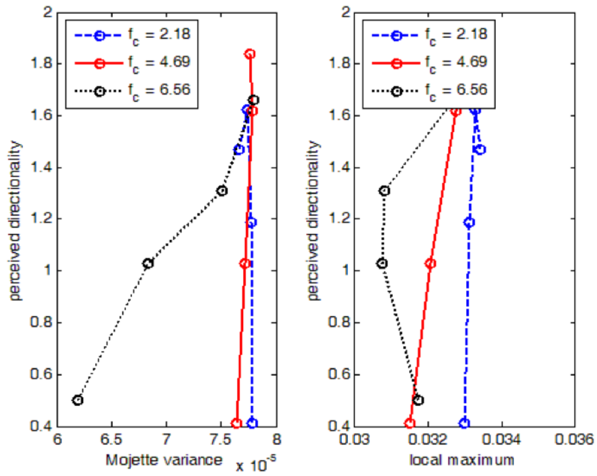

Fig 6. 2-E:different B_W and same f_C

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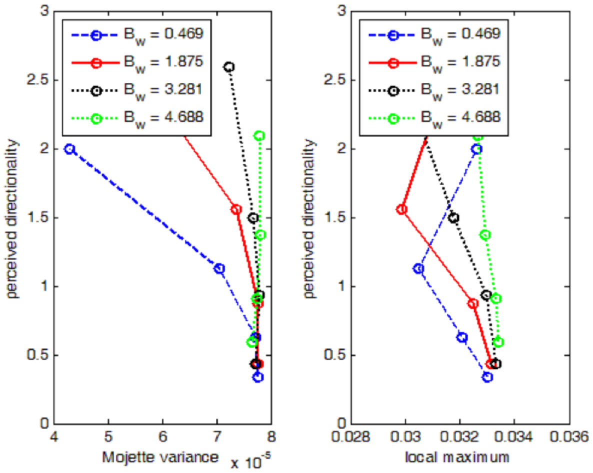

Fig 7. 2-F:different f_C and different B_W

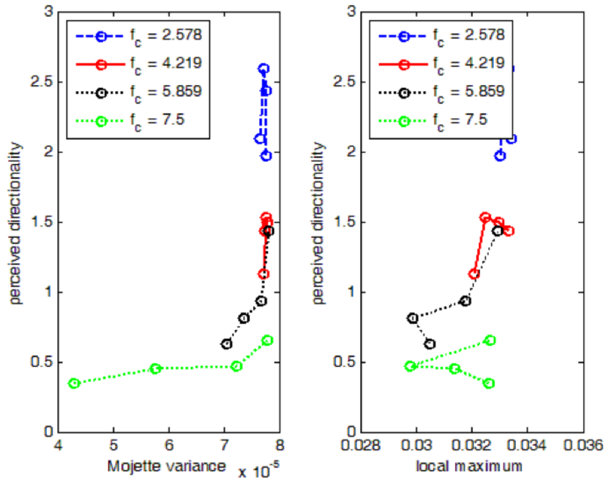

Fig 8. 2-F:different f_C and different B_W

Table 1. Correlation among Perceived directionality , M_V and M_P as σ^2 ,δ,f_C, B_W change

variable	R2	F-Statistics	p-value	Error variance
σ^2	0.9910	20366	<0.01	0.0072
δ	0.2562	5.6827	<0.01	0.2664
f_c	0.8087	52.8583	<0.01	0.1139
B_w	0.5510	15.3427	<0.01	0.1918