Analysis of Human Perception of Surface Directionality

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ABSTRACT

Among many visual characteristics of surfaces, directionality is known to be very important [1, 2, 13, 14] in human perception of textured surfaces. Through series of psychophysical experiments, we investigated effects of various factors on human perception of directionality of synthetic random-phase textured surfaces (see Figure 1) defined by mathematical model. The parameters of the surface model were varied to generate height maps of different directional surfaces, which were then rendered and animated in real-time with controlled illumination. Observers were asked to provide their responses about the directionality of these surfaces during psychophysical experiments. The responses were used to derive a perceptual scale of directionality (perceived directionality) that could be related to parameters of surface model. Statistical tests were carried out to determine if the differences in perceived directionality due to change in the values of parameters are significant.

The parameters, whose effects were investigated, are: angular variance (σ^2), RMS roughness (δ), central radial frequency (f_c) and Bandwidth (B_w). It was found that all four parameters have significant effect on human perception of directionality when their separate effects were investigated and only first three parameters have significant effect when their combined effects were investigated. In the first case, each parameter is varied while holding the other constant and in the second case, all are varied together in one experiment.

Keywords

Perceived directionality, Surface texture, Human perception

1. INTRODUCTION

Human often uses terms like *roughness*, *directionality*, *coarseness* etc. to describe and differentiate textured surfaces. The performance of surface evaluation applications in context of a specific task (for example, automated perception based classification and retrieval of surfaces) depends on how well texture algorithms, which estimate visual characteristics computationally, match human visual system.

Tamura *et al.* [14] were the first who highlighted importance of human perception in texture evaluation applications. After this, several studies have been carried out with the aim of understanding the relationship between human perception of textured surfaces and corresponding computational measures. However, researchers have found it difficult to show a reliable match between such computational measures and human perception of surface characteristics. An important limitation of these studies was that the perceptual investigations of different visual characteristics of textures, including directionality, have been carried out using images from *de facto* data sets such as the *Brodatz* album [4]. The illumination and view point conditions of these images are unknown. However, previous work [3, 6, 7, 10] has shown that these factors affect both human perception of, and computational features derived from, image texture. Furthermore, it is difficult to change the parameters of such surfaces independently of each other in order to determine how perceived directionality is affected by such changes.

Hence, we used synthetic surfaces defined by mathematical model, which allowed us to investigate the effects of varying parameters independently of each other and to conduct the psychophysical experiments under consistent illumination and viewpoint conditions.

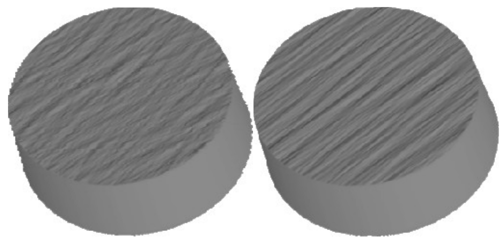

Figure 1 Example Surfaces

2. STIMULI

Various studies [5, 8, 9, 12, 15] suggest that the distribution of frequency components in magnitude spectrum is related to physical and perceptual measurement of various visual characteristics of surface texture including Directionality. Hence, to analyse how various parameters of magnitude spectrum affect human perception of directionality, following class of random phase naturalistic looking surfaces were used.

$$M(f,\theta) = D(f)\,D(\theta)\left(\frac{\delta}{\delta_n}\right)$$

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Where, $M(f, \theta)$, is the magnitude spectrum, $D(f)$ and $D(\theta)$ specify the distribution patterns of the polar frequency components, f and θ, respectively. By varying parameters of , $D(f)$ and $D(\theta)$, effects of various distribution patterns of frequency components on perceived directionality can be analyzed. $D(\theta)$ is used to specify the angular variance (σ^2). $D(f)$ is used to specify the central radial frequency (f_c) and the bandwidth (B_w). The term (δ / δ_n) controls the RMS roughness of the surfaces where δ is the desired RMS roughness of the surface generated and δ_n is a normalisation factor (the RMS roughness of surface height map associated with the magnitude spectrum as $D(f)D(\theta)$. The effects of varying four parameters were investigated psychophysically (see Figure 2 for illustration). They were: RMS roughness (δ), Angular variance (σ^2), Central radial frequency F_c), Bandwidth (B_w).

3. METHOD

The Lambertian surfaces were rendered under constant illumination and animated to follow a prescribed 'wobble' in order to provide the observer with motion parallax depth cues (as used by Padilla et al [11]). Five psychophysical experiments were carried out to analyse human perception of surface directionality. In the first four experiments, separate effects of parameters were investigated and in the fifth experiment, combined effects of four parameters were investigated. Due to combinatorial limitations, only pairs of parameters were varied together in the fifth experiment i.e. three and four-way interactions of parameters were not investigated. The direct-ratio estimation method and the method of constant stimuli or pair-wise comparisons were used to obtain the perceived directionality of the surfaces in different psychophysical experiments depending upon the number of surfaces used in the particular experiment. In all experiments observers provided the sense-ratio i.e. the ratio of sensory magnitudes of directionality of two surfaces displayed side by side.

4. RESULTS AND CONCLUSIONS

To determine how significantly the parameters or their two-way interactions affect the perceived directionality, one-way and two-way repeated measures ANOVA were carried out. The results of experiments evaluating separate effects of parameters indicated that all four parameters (σ^2, δ, f_c and B_w) affect the perceived directionality significantly. However, the results of an experiment evaluating combined effects of parameters indicated that σ^2, δ and f_c affect the perceived directionality significantly and the interaction (two-way) between these three parameters do not have any significant effect. B_w was found to be significant only at low value of f_c and the effect size was also low compared to the effect sizes of other parameters. The relationship between the perceived directionality and these parameters showed that the perceived directionality increases linearly as $\log(\sigma^2)$ decreases, δ increases and f_c increases. These results can be used to derive a mathematical model of perceived directionality which can be used in applications such as automated perception based texture classification or retrieval as the parameters of the model can be mathematically estimated from unknown random phase surfaces.

5. ACKNOWLEDGMENTS

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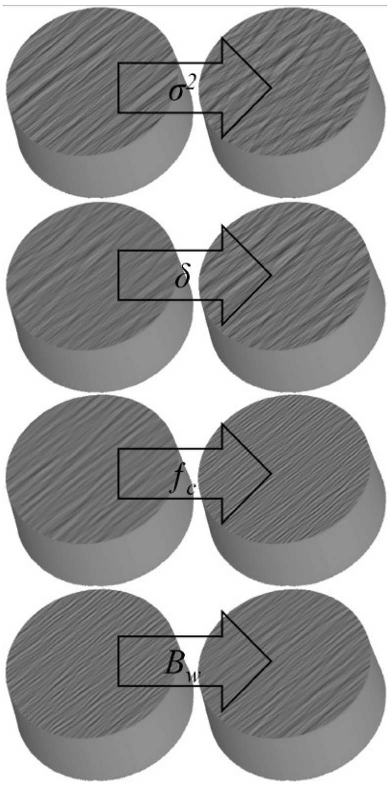

Figure 2 Effect of various parameters on perceived directionality