Fundamental Study on the Roughness Contrast of Texture

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Abstract: This paper aims to demonstrate the existence of the roughness contrast of texture, in addition to color contrasts, in establishing the fundamental theory of texture coordination. Much research has been conducted on texture for the purpose of understanding its psychological impact and the development of the index of fundamental psychological evaluation. However, previous studies have been for a single type of texture, and very little research has been done on the visual effects caused by the mixture of multiple textures. To design real spaces or products, designers have to consider the combination of various textures. Therefore, the theory of texture coordination is needed in addition to the theory of color coordination. In this research, we transformed the roughness of texture into dotted patterns and attempted to verify that the combinations of the patterns have contrast effects, just as color does. As a result of our experiment, we verified the contrast effects of the roughness of texture, and we identified the three dominant elements that cause the contrast effects: (1) contrast by dot size, (2) contrast by density of dots, and (3) contrast by direction of the texture.

Key words: texture, texture coordination, roughness contrast, color contrast, dotted pattern

1. Introduction

When we look at an object, our perception is not a mere relationship between the observer and the object. One can never see only the single object. Everything is perceived with all the various elements within the field of view. Moreover, the textures and colors of these other elements can be key factors that affix familiarity or preference to the spaces or products that we design. This subject has been studied for a long time in various fields, such as product design, interior design, and architecture, because the concept of texture coordination to harmonize the elements are important in designing various objects and spaces and in selecting materials. In particular, two main streams of research studies emerged, in terms of the use of texture in the architectural field: one is the psychological evaluation of the effects of texture and the other is the establishment of a basic evaluation index. However, most of these studies focused on the perception of a single texture; therefore, few research studies discuss the visual effects when two or more textures are adjacent to each other.

This study adapts the basic theory of color coordination to establish a theory of texture coordination, which is one of the important components that form the observer's impression of the space and the object. The texture is discussed from the viewpoint of coordination. Moreover, the impression of texture greatly depends on the observer's distance from the object. For example, when an observer views a concrete wall texture at close proximity, the irregularity of the aggregate is visible, giving the impression of a rough wall. The farther the distance between the observer and the wall, the less rough the texture seems, until it finally resembles a plain surface. That is, the texture can be defined from various distances and at different scales.

The purpose of this research is to obtain a basic understanding of the interrelation between different textures. The innovation of this research is to discuss the contrast effects of the roughness of texture, from the coordination viewpoint.



Figure. 1-1 Texture perception varies depending on the observation distance

2. Perception of texture

This chapter explains the perception of texture. Some research studies revealed that the complexity of the texture perception could be described with a simple mechanism. Texture perception is a psychological judgment that comes from both a sense of sight and a sense of touch, which are expressed through the visual appearance of the surface properties, especially the irregularity of the object. This suggests that perception of the same texture may differ from one observer to the next. Moreover, the visual appearance can also change depending on the observation distance, the lighting conditions, and the observer.

Contrary to the theory of the complexity of texture perception, Motoyasu [1] recently performed a series of research studies on how the brain perceives texture, and these studies illustrated the simplicity of man's perception of texture. The brain judges the texture properties, such as brightness, gloss, and transparency, with simple 2D graphical information, such as the histogram strain and the contrast of the brightness. This fact validates our decision to use simple geometric dot patterns to model the texture image for verification in this research.

2.1 Perception mechanism of textures

Texture perception is divided roughly into the following two processes. (1) The "optical process," where light reflects off the surface of the object depending on the surface properties, and the reflected light reaches the rod cell of the retina. (2) The "visual information processing process," where the brain receives and processes the light information to judge the texture.

Figure 2-1 shows the process of perceiving texture, including the intervening factors.



Figure. 2-1 Perception mechanism of textures

The simplicity of (2) the "visual information processing process ", for brain to judge the texture properties from the image on the retina, is illustrated by Motoyasu's studies, as previously mentioned.

This paper aims to demonstrate the existence of the roughness contrast of texture in this "visual information processing process" by using simple geometric dot patterns to model the texture image for verification.

3. Color contrasts

This chapter describes the basic theories of the color coordination that were applied to texture coordination in this research. Previous research studies have established that we do not perceive only a single color, because the adjacent color and the background color are always perceived with the central color as a set. The same color can be perceived as a different one, depending on the viewing conditions. Likewise, two different colors can be perceived as a same color, depending on the viewing conditions. This shows that we perceive color as a relative value in contrast to the environment.

3.1 Brightness contrast

The brightness contrast is a contrast effect where the brightness of the color seems to change in the opposite direction of the background color. This is one of the simultaneous contrasts identified by Michel Eugène Chevreul, and it refers to the manner in which the colors of two different objects affect each other. In Figure 3-1, the two

inner rectangles are exactly the same shade of grey, but the left one appears to be a lighter shade than the right one due to the contrast provided by the outer rectangles.



Figure.3-1 Brightness Contrast

3.2 Hue contrast

Simultaneous contrast is typically applied to chromatic color. When an observer gazes at the pattern on the left side of Figure 3-2, the retinal cones that respond to the color blue become activated. The color yellow is the physiological opposite of blue; therefore, the green color in the middle is perceived with an additional yellow tint. The opposite happens in the pattern on the right of Figure 3-2. As a result, the squares with the same green colors are perceived differently. This contrast effect occurs because the retinal cone adapts to a color quickly, and the negative afterimage appears.



Figure.3-2 Hue Contrast

3.3 Saturation contrast

In addition to the contrast of Brightness and Hue, it is well known that saturation contrast exists as one of the simultaneous contrasts.

4. Texture contrast

In this chapter, we set up the hypotheses to establish a theory on texture coordination by applying the basic theory of color coordination to texture coordination. If we replace "color" in "color contrast" with "texture," we can infer that texture perception can also change as a result of the mutual interferences that exist between the central texture and the surrounding components. In addition, the existence of the dominant factors which trigger the contrast, like 'Brightness', 'Hue' and 'saturation' represent color contrast.

4.1 Roughness contrast

Texture perception can be expressed in various ways, such as glaze, roughness, transparency, and softness. Here, we focus on the relative perception of the roughness of textures and verify its contrast effect. The rougher the background object is, the smoother the texture of the object seems. This hypothesis is indicated in an existing study by Kitamura [2], who researched the contrast effect caused by change of the light condition. However, that is not a study focused on the effect on a texture surfaces from the mutual surrounding texture. In the discussions about the area effect of textures in the research, Kitamura suggested that the possible cause might be the observers' unconscious comparison of the roughness of an object with that of the background.

Figure 4.1 shows texture images of sandstone with three different levels of roughness (A, B, C). We excerpted these images from The book about Dressed stone by Theodor Hugues [3], applied gray-scale filtering, and matched their gray levels. The roughness increases from left to right.

We derived our hypothesis based on an experiment using these three texture images. Figure 4.2 shows a pair of the texture images used in the experiment. Each image is a combination of two different texture images from Figure 4.1. (A+B, C+B) Here, the clipped image of B is in the center of the left and right images with a background of A and C, respectively. The center picture of B on the left side appears as if it were rougher than the one on the right side. Therefore, we hypothesize that we perceive roughness of texture as a relative value in contrast to surrounding components. This hypothesis was validated with questionnaires, as described in the following chapters.



Figure 4.1 Sandstone textures with different external roughness

5. Verification of perception of roughness comparison

We transformed the roughness of texture into geometric dotted patterns to verify that the combinations of the pattern models have contrast effects like color. As a result of the experiment, we confirmed the contrast effects of the roughness of texture, and we identified the three dominant elements that cause these effects.

5.1 Method and condition of verification

In Chapter 2, we proved the validity of using simple geometric dot patterns* to model a texture image for our experiment. Similar to the samples used to illustrate color contrasts, we used pairs of square models measuring 75 mm on each side. At the center of each square, we embedded a smaller square measuring 30 mm on each side. Each square had a dotted pattern, and all the inner squares had the same pattern, while the outer squares had different patterns. Our test subjects viewed the squares at a constant distance from the samples. Our goal was to determine whether any contrast phenomenon occurs for the inner squares.

5.2 Parameters

A series of research studies by Kotani and Chatani [5], using the geometric dot pattern, quantified the effect of certain factors on roughness perception. Based on their dotted patterns, the parameters for this experiment were selected to best express the physical irregularity and cross-sectional shape of the pattern.

a) Density of elements (number of dots per degree of visual angle = irregularity/frequency

- b) Shadow strength of elements = average height
- c) Arrangement of elements = variability and unevenness of the irregularity
- d) Difference of element diameters = variance of radius in irregular part
- e) Shape of elements = profile line of the irregular part
- f) Angle of elements = direction of the irregularity
- g) Brightness of elements = brightness of the irregularity
- x) Diameter of elements = radius of the irregular part
- y) Center-to-center spacing of elements = average interval of peak



Figure 5-1 Texture modeling: Texture image



Figure 5-2 Texture modeling: dot pattern

5.3 Sample of experiment

(1) Creating dot patterns

To methodically change the densities of elements, various dot patterns were created and printed on plain white paper. The basic dot patterns have a large number of square or geometric figures (elements) plotted on a gray background. The densities of elements were changed within a spatial frequency range in the Vertical and horizontal directions, so that viewers can easily perceive the dotted pattern from 50 cm away. Spatial frequency indicates the average interval between dots. Figure 5-3 shows the basic dot patterns with spatial frequencies of 2, 3, and 4, which are in the middle of the range. These patterns were used as templates when making others for the different parameters.

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	Basic dot pattern 2	Basic dot pattern 3	Basic dot pattern 4
Diameter of a dot (mm)	1.50	1.00	0.75
Distance between dots (mm)	2.25	4.00	0.56
Number of dots ()	289	650	1156
Area of a dot(m ²)	4.36	2.91	2.18
Area density of dots(%)	11.56	11.56	11.56

Figure.5-3 Basic dot patterns: densities of elements

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	Particle size–2S	Particle size–2M	Basic dot pattern 2
Diameter of a dot (mm)	0.75mm	1.00	1.50
Distance between dots (mm)	0.56	1.00	2.25
Number of dots (piece)	289	289	289
Area of a dot (m)	4.36mm	4.36	4.36
Area density of dots(%)	2.88	5.14	11.56
			Interval 41
	Basic dot pattern 4	Interval–4M	Interval–4L
Diameter of a dot (mm)	0./5mm	0./5mm	0.75
Distance between dots (mm)	0.56	0.50	0.50
$\frac{1}{1}$	2 19mm	2.01	4 26
Area density of dots (94)	2.101111	2.91 6.47	4.30
Area density of dots (%)	11.30	0.47	2.00

11.566.47Figure.5-5 Center-to-center spacing of elements

(2) Creating experiment samples

Experiment samples were produced using the various patterns, as illustrated in Figure 5-6. The samples shown in Table 5-1 were generated using three different dot patterns and by changing each parameter systematically. The dot pattern in the area Sa within the square La is the same as the dot pattern in the area Sb within the square Lb.





(3) Outline of experiment

The dot patterns shown in Table 5-1 were presented to the test subject, who was asked if there existed a perceived difference in terms of each parameter. The answers were ratings of "not at all," "probably not," "undecided," "probably yes," and "definitely yes."



Presented image B Figure 5-8 Guidance diagram of experiment

For example:

Q2. Please compare 'Sa' and 'Sb.'

Do you think there is a difference in dot sizes between 'Sa' and 'Sb'?

A. "not at all," "probably not," "undecided," "probably yes," "definitely yes"

The test subjects were 21 students from Kyoto University (13 males, 8 females) with an average age of 24 years and a minimum naked/corrected visual acuity of 0.8 (16/20) for both eyes. They were asked to view the patterns from a distance of 50 cm.



5.4. Summary of experiment result

The number of people who responded "not at all," "probably not," "undecided," "probably yes," and "definitely yes" were labeled as AN, N, B, Y, and AY, respectively. Figure. 5-10 shows the ratio of people who answered "probably yes" and "definitely yes" to the total number of test subjects (Y+AY)/(AN+N+B+Y+AY). Figure. 5-11 shows the term weighting number from -2 to 2, $AN \times (-2) + N \times (-1) + B \times (0) + Y \times (1) + AY \times (2)$.



Figure.5-10 Ratio of people who answered "probably yes" and "definitely yes"



Figure.5-11 Contrast value

5.5. Consideration of each index

Q1) Comparison of perceived roughness



Figure.5-12 Test Pattern with its result (comparison of perceived roughness)

Question 1 included an image used to verify the contrast effect. All test subjects responded that they could clearly perceive a difference in roughness between the two inner squares.





Figure.5-13 Test Pattern with its result (comparison of size of element)

Question 2 focused on the number of the elements, as well as the entire gray level change. According to responses to this question, 91% of the test subjects perceived a difference in particle size between the two inner squares. The law of holistic perception from Gestalt psychology could be the key factor that influences the particle size contrast effect. If elements are close together, they could be perceived as a single mass.

In this question, the distances between elements are equal but the sizes of the elements vary, so the distances between the elements seem to change due to the size differences of the elements. The sizes of the dots range from large to small and labeled as follows: "i) basic dot pattern," "ii) particle size M," and "iii) particle size 2S." In the image on the right, a subjective outline is perceived, separating the surrounding area from the inner area. This outline heightens the sense of the separation of inside and outside as well as emphasizes the contrast effect. The gray level varies in this image, and the appearance of the outline enhances the brightness. That is, the dark area becomes darker due to the contrast in brightness.

Q3) Comparison of intervals of elements

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 	Positive Ratio : 95%
	Cotrast value : +31

Figure.5-14 Test Pattern with its result (comparison of intervals of elements)

Question 3 deals with the distance between element centers, and the overall gray level changes as well. Of all the test subjects, 95% perceived a difference in density between the two inner areas. The law of holistic perception from Gestalt psychology could help to explain the effect here as well. The sizes of the dots ranged from large to small and were labeled as follows: "i) basic dot pattern 4," "ii) interval 4M," and "iii) intervals 4L." Unlike the image pair in Question 2, the subjective outlines that separate the inner area from the surrounding area can be seen

in both images. This subjective outline in the picture on the left can be perceived as smaller than the actual boundary, whereas it is perceived as bigger in the picture on the right. Two possible reasons are suggested. First, the different gray levels trigger the brightness contrast. Second, the density contrast effects may be perceived stronger around the boundaries.

Figure.5-10 shows the ratio of positive answers given by the test subjects. We can see the existence of the contrast effect, based on Questions 1, 2, 3, and 8, especially with Question 1, which received 100% positive feedback from the test subjects.

6. Conclusions

As a result of this experiment, we verified the contrast effects of the roughness of texture, and we identified the three dominant elements that cause these effects:

(1) Contrast by the dot size,

(2) Contrast by the density of dots,

(3) Contrast by the direction of texture.

The extraction of' (3) contrast by the direction of texture' includes the condition that the direction of the elements/dots should be moderate and not excessive. However, the main direction should neither be vertical and nor horizontal. According to research by Komuro[6], these three dominant factors of the visual roughness contrast are very similar to the dominant factors for the roughness perception of the texture itself. In addition to the aforementioned conclusions:

(A) When the background area is dark and the object area is brighter, the contrast effect is perceived more easily compared to the opposite scenario.

(B) The experiment results on shadow effect of the surface irregularity creates (Q.6, Q.7) were evenly-divided. More research is needed in the future, because this index could become a dominant factor as well.

We determined that the roughness contrast of texture is not as strong as color contrast, which suggests that a hierarchy of color and texture coordination exists in design.

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