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Visual Complexity Perception and Texture Image Characteristics

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***Abstract*—Visual complexity perception is an important issue in the fields of psychology and computer vision because it leads to the better understanding of the nature of human perception as well as the properties of the objects being perceived.**

In this study, five important characteristics of texture images that affect visual complexity perception are identified: regularity, understandability, roughness, directionality, and density. Among these, understandability is a deterministic characteristic, which reflects the viewer's prior knowledge and experience. These characteristics significantly affect the visual complexity perception of texture images. In order to achieve our objective, we carried out two experiments involving visual complexity assessment and paired comparison evaluation with 30 respondents. We applied correlation analysis, factor analysis, and multidimensional scaling to analyze the collected data. The experimental results showed that most of the human impressions of visual complexity can be explained by the perceived characteristics of texture images.

***Keywords*-visual complexity; *Kansei*; texture perception; multidimensional scaling;**

I. Introduction

Evaluation of visual complexity aims at investigating humans' "*Kansei*" of the complexity of the visual scene. It can be extended to include esthetics, visual psychology, and cognitive systems. In addition, research into visual complexity is useful in understanding the mechanism of human perception and is of interest to real applications such as image compression and information theory [1].

Visual scenes are composed of numerous textures, objects, and colors. Although scenes are visually complex, human beings are able to form a coherent perception of complexity and identify a complex image or object at a glance [2]. This provokes the question of how human beings extract information from visual scenes and which characteristics of images affect humans' perception of visual complexity.

Many studies of visual perception have featured texture images [3]–[7]; however, little research has been carried out into the visual complexity of texture images. Motivated by the above considerations, we aim to identify the characteristics of texture images that affect humans' perception of visual complexity.

In order to achieve this objective, we performed two experiments involving visual complexity assessment and paired comparison evaluation. Thirty respondents participated in the experiments and evaluated the visual complexity of textures and described the criteria that they used to perceive complexity. The respondents marked five pairs of comparisons on a 7-point Likert scale. The techniques of correlation analysis, factor analysis, and multidimensional scaling (MDS) were employed to further analyze the experimental results. In this study, five important characteristics of textures that affect visual complexity perception are identified: regularity, understandability, roughness, directionality, and density. The first four characteristics have significant effects on visual complexity perception. In the case of textures with similar level of regularity or directionality, understandability dominates the evaluation of visual complexity.

II. Visual complexity

The study of human visual perception of complexity is an important issue in the fields of psychology and computer science because it leads to the better understanding of the nature of human perception as well as the properties of the objects being perceived.

However, what is the definition of visual complexity? Some researchers have defined the concept of visual complexity in their studies [8]–[10]. Scha and Bod described complexity as being largely a function of the number of elements that an image consists of and their order of placement in the image. Heylighen considered that the perception of complexity is correlated with the amount of variety in the visual stimulus. Heaps and Handel defined complexity as "the degree of difficulty in providing a verbal description of an image." However, although some researchers define visual complexity in their own way, its concept remains vague and ill-defined.

Many investigations have been carried out into visual complexity. In the field of psychology, Olive et al. investigated the perceptual dimensions of the visual complexity of scenes. In this study, 34 participants performed an experiment using the method of hierarchical grouping of indoor scenes. Results showed that visual complexity is represented by several dimensions such as number of objects, clutter, openness, symmetry, organization, and variety of colors [2].

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In the field of computer science, researchers have focused on evaluating visual complexity by using mathematical methods [1], [11]–[13]. Andrienko, Brilliantov and Kurths developed a complexity measure based on mean information gain and applied it to two-dimensional (2D) structures. In addition, Patel and Holt compared a pattern measure proposed by Linger and Salingaros with the respondents' perception of the complexity of background image scenes. The results showed that a high and positive correlation existed between mathematical measures and the subjects' perception. Furthermore, Rigau, Feixas and Sbert proposed a new framework for investigating the complexity of an image by using information theory. Cardaci et al. presented a fuzzy model of visual complexity that fitted well with subjective measures of complexity. These studies had made some progress in measuring visual complexity by using information theory and pattern methods.

With respect to the visual complexity perception of textures, no studies have been conducted so far. Therefore, it is necessary and meaningful to identify a set of perceptual cues that are used by human beings to perceive the visual complexity of textures.

III. Experiments

In this study, two experiments involving visual complexity assessment and paired comparison evaluation were carried out.

A. Experimental set-up

1) Respondents: A total of 30 respondents (15 male and 15 female) from Hiroshima University with a background in information engineering, education, management, and social economics participated in the experiments. Although some of the respondents were engaged in image science, they were unaware of the purpose of this study. Their age ranged from 20 to 35 years. All respondents had normal or corrected-to-normal vision.

2) Apparatus and Stimuli: Twenty texture images were selected for the experiments (Fig. 1). The sample images were obtained from a standard source, Brodatz's album [14], which has been widely used in the fields of texture analysis and visual perception. Each sample image was arranged randomly on a single screen and shown to the respondents one by one. The screen was part of a 15 inch 4:3 LCD monitor. The experiments were conducted in a laboratory with normal illumination. The respondents were allowed to choose their own preferred position and viewing angle.

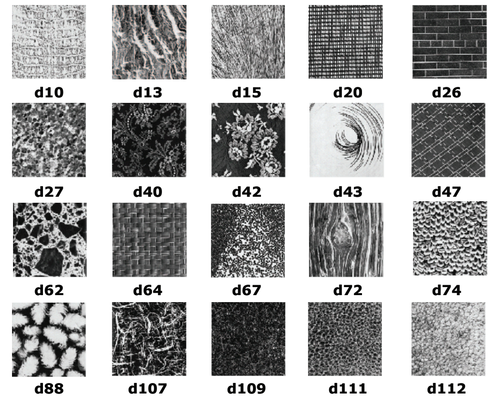

Figure 1. Images used in the experiments

Table I
SUMMARY OF VERBAL DESCRIPTION FROM 30 RESPONDENTS

Descriptions	*Frequency*
Regularity	27
Understandability	20
Density	17
Directionality	15
Contrast	10
Different texture primitives	9
Structure	8
Symmetry	6
Nonuniform	4

B. Visual complexity assessment

The first experiment was briefly described to the respondents and then the texture samples were displayed two times. On the first time, each respondent viewed all samples one by one with no time constraint. On the second time, for each texture sample, the respondents were asked to score complexity on a 7-point Likert scale by using their own knowledge and judgment. The 7-point scale ranged from 1 (very simple) to 7 (very complex). After scoring, the respondents were asked to verbally describe the characteristics of textures that affect their evaluation of visual complexity perception. Each verbal description was recorded and classified into the corresponding criterion. Table I summarizes all the criteria given by the respondents and the frequency of criteria that they used to perceive the complexity of texture images.

Table I shows that the major characteristics of textures that affect human visual complexity perception are regularity, understandability, density, and directionality. Other characteristics such as contrast, different texture primitives, and structure have a slight effect on the respondents' evaluation of complexity.

C. Paired comparison evaluation

The method used in this experiment was paired comparison evaluation, which is widely used in the field of psychology [15]. From the first experiment, we acquired the primary characteristics of textures that affect the respondents' evaluation of complexity. Therefore, we conducted the second experiment to analyze the relationship between these characteristics and visual complexity perception by

Figure 2. The 7-point rating scale used in the experiment

conducting a series of paired comparisons.

Five pairs of adjectives were used for the paired comparison evaluation, namely irregular versus regular, low density versus high density, nondirectional versus directional, smooth versus rough, and understandable versus abstract. The five pairs of comparisons are defined as follows. (1) Regularity: irregular versus regular. Regularity was defined as variation in the placement rule of texture primitives, in agreement with the definition of regularity in Tamura's research. (2) Density: low density versus high density. Density was used for testing whether the perceived primitives and edges were dense or sparse. (3) Directionality: nondirectional versus directional. The directionality of texture was related to primitive shape and the global placement rule, in agreement with Tamura et al. (4) Roughness: smooth versus rough. Roughness was not verbally described by the respondents in the first experiment; however, roughness was defined as a combination of contrast and coarseness in Tamura's research [3]. Hence, we adopted roughness and smooth as one of the paired comparisons instead of contrast and different primitives described in the first experiment. This property is fundamentally related to touch, however; when we observe the textures, we are able to compare them in terms of whether they feel rough or smooth. (5) Understandability: understandable versus abstract. This is related to the respondents' prior knowledge and experience.

This experiment was conducted under the same conditions as those in the first one. After an introduction to the experiment and a brief explanation, the respondents were instructed to view all images one by one. For each pair of comparison, the respondents scored complexity perception on a 7-point Likert scale. The scale and its anchor-point phrases are shown in Fig. 2. The order of the presentation of the samples was randomized to avoid any order effect. Table II [1] shows the average score of complexity and different paired comparisons evaluated by the respondents. The texture images were sorted in ascending order by average evaluation score, and these results are shown in Table III.

Table II
AVERAGE SCORES OF COMPLEXITY AND DIFFERENT PAIRED COMPARISONS

	Com	*Reg*	*Den*	*Dir*	*Rou*	*Und*
*d*10	4.27	4.07	4.47	4.67	4.47	3.70
*d*13	5.80	1.70	5.00	3.27	6.07	5.03
*d*15	4.77	2.47	5.70	4.23	4.93	4.43
*d*20	4.07	6.10	6.17	6.30	4.10	3.67
*d*26	1.43	6.53	2.53	6.63	2.87	1.07
*d*27	5.80	2.43	5.27	1.87	5.20	5.20
*d*40	3.53	3.43	3.40	3.40	3.40	2.17
*d*42	2.93	4.17	2.50	3.60	3.10	1.50
*d*43	3.07	2.53	1.83	4.37	2.33	3.90
*d*47	2.47	6.53	2.80	6.60	2.13	2.00
*d*62	4.37	2.43	3.73	2.23	4.70	4.80
*d*64	3.03	6.13	5.07	6.30	3.93	1.73
*d*67	3.30	3.53	5.33	3.03	3.40	3.50
*d*72	5.27	2.73	4.73	4.87	5.30	3.23
*d*74	4.10	4.27	5.37	3.23	3.53	2.93
*d*88	3.07	4.60	3.17	3.47	2.83	2.57
*d*107	5.50	1.57	4.80	1.38	5.20	6.07
*d*109	5.47	2.33	5.07	1.43	5.00	6.10
*d*111	5.50	2.77	6.47	2.07	4.40	4.93
*d*112	5.63	2.83	5.97	2.03	4.60	5.40

Table III
AVERAGE SCORES FOR TEXTURE IMAGES IN ASCENDING ORDER

Com	*Reg*	*Den*	*Dir*	*Rou*	*Und*
*d*26	*d*107	*d*43	*d*107	*d*47	*d*26
*d*47	*d*13	*d*42	*d*109	*d*43	*d*42
*d*42	*d*109	*d*26	*d*27	*d*26	*d*64
*d*64	*d*62, *d*27	*d*47	*d*112	*d*88	*d*47
*d*88, *d*43	*d*15	*d*88	*d*111	*d*42	*d*40
*d*67	*d*43	*d*40	*d*62	*d*67	*d*88
*d*40	*d*72	*d*62	*d*67	*d*40	*d*74
*d*20	*d*111	*d*10	*d*74	*d*74	*d*72
*d*74	*d*112	*d*72	*d*13	*d*64	*d*20
*d*10	*d*40	*d*107	*d*40	*d*20	*d*67
*d*62	*d*67	*d*13	*d*88	*d*10	*d*10
*d*15	*d*42	*d*64, *d*109	*d*42	*d*111	*d*43
*d*72	*d*10	*d*27	*d*15	*d*112	*d*15
*d*109	*d*74	*d*67	*d*43	*d*62	*d*62
*d*111	*d*88	*d*74	*d*10	*d*15	*d*111
*d*107	*d*20	*d*15	*d*72	*d*109	*d*13
*d*112	*d*64	*d*112	*d*20, *d*64	*d*107, *d*27	*d*27
*d*13, *d*27	*d*26, *d*47	*d*20	*d*47	*d*72	*d*112
		*d*111	*d*26	*d*13	*d*107
					*d*109

IV. Analysis and Discussion

From the visual complexity assessment experiment, we obtained the major characteristics of textures that affect visual complexity perception. In Table I, the frequency indicated the strength of the criteria that the respondents used to perceive the complexity of textures (i.e., most commonly used, often used, or seldom used). Ninety percent of the

[1] *Com*:*Complexity*;*Reg*:*Regularity*;*Den*:*Density*; *Dir*:*Directionaltiy*;*Rou*:*Roughness*;*Und*:*Understandability*

Table IV
CORRELATION MATRIX OF PERCEPTUAL CHARACTERISTICS OF TEXTURES AND VISUAL COMPLEXITY

	Reg	*Den*	*Dir*	*Rou*	*Und*
Com	−0.7944*	0.5904*	−0.7108*	0.8791*	0.8769*
Und	−0.8382*	0.4836	−0.7634*	0.7118*	
Rou	−0.7526*	0.4802	−0.4908		
Dir	0.7158*	−0.3864			
Den	−0.1769				

* $p < 0.01$

respondents regarded regularity to be the main characteristic influencing their complexity assessment. In addition, high frequencies were recorded for understandability (almost 67%), density (approximately 57%), and directionality (50%). Thus, it is concluded that regularity, understandability, density, and directionality are the main characteristics of textures that affect human visual perception of complexity in textures. Among these characteristics, regularity, density, and directionality reflect the primary characteristics of texture images, whereas the understandability of textures is related to respondents' prior knowledge and experience. Hence, we can conclude that visual complexity perception is related to objective characteristics of textures as well as humans' subjective knowledge.

A. Correlation analysis

We used a correlation analysis to investigate the correlation between characteristics of textures and visual complexity. The results of the analysis are shown in Table IV.

Table IV shows that complexity is strongly correlated with understandability ($r = 0.8769$, $p < 0.01$), which indicates that prior knowledge and experience considerably affect human perception of complexity; this is in agreement with the definition of complexity in Webster's dictionary, i.e., a complex object is one that is difficult to understand or deal with. Interestingly, although roughness was not mentioned in the first experiment, it shows a high correlation ($r = 0.8791$, $p < 0.01$) with the perception of complexity. This might be partly because the respondents perceived roughness to be associated with the imagination of texture images (which relates to understandability); this is demonstrated by the correlation between roughness and understandability ($r = 0.7118$, $p < 0.01$).

Figure 3 clearly shows that regularity and directionality have negative correlation with visual complexity perception. On the contrary, roughness and understandability have a strong positive correlation with visual perception of complexity. For instance, texture d107 was perceived to be fairly complex because it was the most irregular and had the least directional texture. In addition, texture d13 was perceived to be very complex because of its characteristics such as irregular placement, rough feeling, and hard to understand.

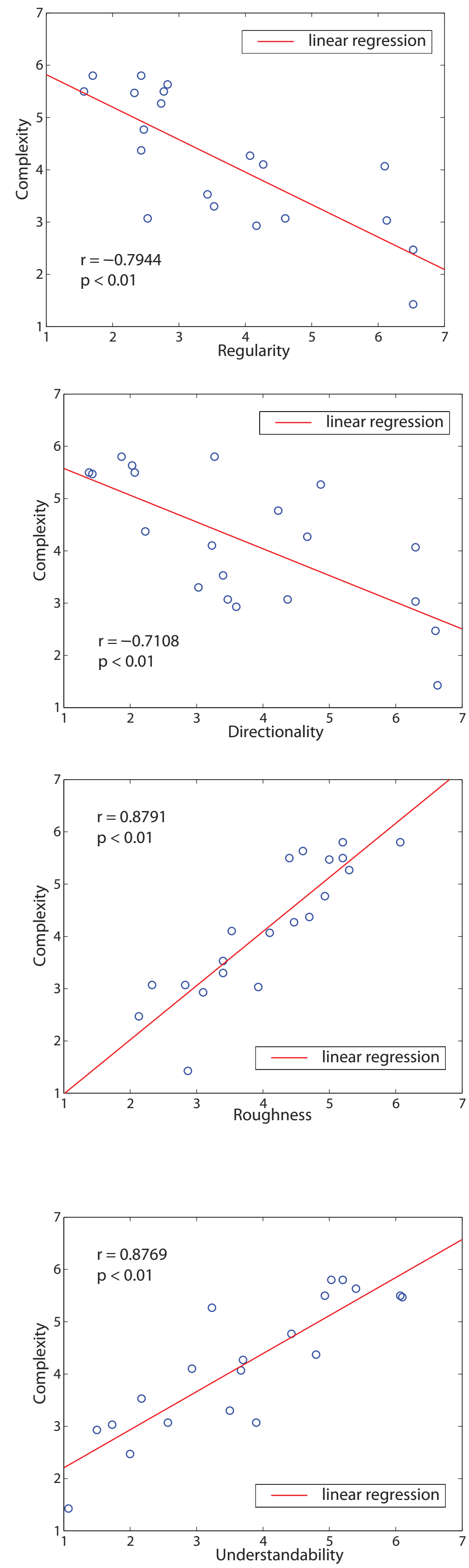

Figure 3. Relationships between different characteristics of textures and visual complexity

Table V
FACTOR LOADINGS WITHOUT ROTATION

Variables		*Factor Loadings*	
		Factor1	*Factor2*
Irregular	*Regular*	−0.9897	0.1243
Low density	*High density*	0.3769	0.9180
Nondirectional	*Directional*	−0.8284	−0.0044
Smooth	*Rough*	0.7106	0.4301
Understandable	*Abstract*	0.8339	0.2627
Contribution(%)		60.16	22.25
Accumulative Contribution(%)		60.16	82.41

Visual complexity is a function of not only each individual characteristic but also interactions between them, which is demonstrated by the correlation coefficients of perceptual characteristics in Table IV. The correlation between regularity and understandability is high (r = –0.8382, p < 0.01). In general, textures characterized by regular placement are easy to understand, leading to a perception of less visual complexity. Similarly, the correlation between directionality and understandability is also very high (r = –0.7634, p < 0.01). An interaction exists between roughness and understandability, regularity and roughness, and directionality and roughness. Therefore, it is suggested that the respondents used a different combination of these characteristics while evaluating the visual complexity of textures.

In some cases, one or two characteristics of textures dominated the respondents' evaluation of visual complexity. In the experiments, textures d42 and d26 were evaluated as having similar level of visual complexity, although d42 was more irregular and less directional. For d42, its characteristic of understandability led the respondents to assess its complexity as being similar to that of d26. For texture d43, although it was perceived as being smoother, having lower density, and being more directional, its abstract understandability property resulted in it being perceived to be more complex than d42. In these cases, understandability dominated the respondents' evaluation. Moreover, the high correlations between understandability and three other salient characteristics also demonstrated that prior knowledge and experience have significantly affect the visual perception of complexity of texture images.

B. Factor analysis

For each texture sample, the evaluated values of five paired adjectives were statistically standardized. To investigate the importance of perceptual characteristics for visual complexity perception, these values were analyzed using factor analysis. Principal component analysis was employed for defining a set of factors. Finally, two factors were extracted. The results of factor loadings are shown in Table V.

This table shows that regularity, directionality, roughness,

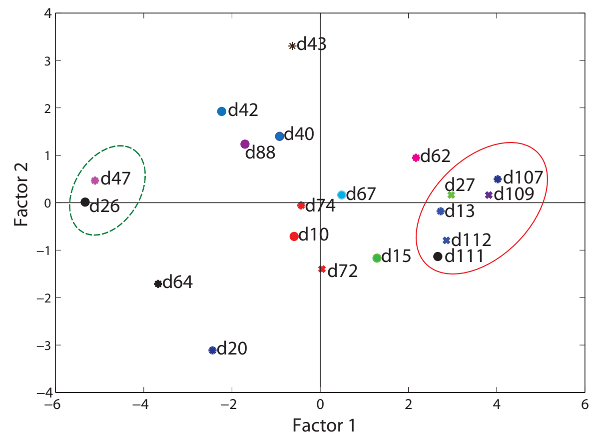

Figure 4. Multidimensional Scaling map

and understandability contribute considerably to explaining factor 1, and density contributes significantly to explaining factor 2. Accumulative contributions of two factors show that 82.41% of human perceptions of visual complexity can be explained by these two factors. Factor 1, which has a contribution of over 50%, plays a particularly influential role in affecting human visual perception of complexity.

C. Multidimensional scaling

After applying factor analysis, we used MDS to diagrammatically display the results of the evaluation. Two dimensions (defined using factor analysis) were used to create the MDS map, as shown in Fig. 4.

The MDS map provides the following graphical representation of the texture samples: along the horizontal axis, the samples are mapped according to factor 1 (regularity, directionality, roughness, and understandability), with the more simple (regular, understandable, and directional) samples on the left and the more complex (irregular, abstract, and nondirectional) samples on the right. Along the vertical axis, the samples are positioned according to factor 2 (density), with the lower density samples at the top and the higher density samples toward the bottom.

MDS uses similarities and dissimilarities among the complexity evaluations given by respondents and provides a representation of visual complexity perception in a 2D map. As seen in Fig. 4, the left dotted circle and right solid circle correspond to respondents' definitions of a simple group and a complex group, respectively. In addition, the points within both circles are clustered horizontally, which appears to suggest that visual perception of complexity is deterministically affected by factor 1.

V. Conclusion

In this study, five important characteristics of texture images that affect visual complexity perception are identified:

regularity, understandability, roughness, directionality, and density. Among these characteristics, understandability plays a deterministic role in influencing human visual complexity perception.

Visual complexity perception is related to both the objective characteristics of textures and humans' subjective knowledge. Using factor analysis, the results showed that 82.41% of human impressions of visual complexity perception can be explained by the perceived characteristics of textures. Regularity, understandability, directionality, and roughness were shown to be the most influential characteristics affecting visual complexity evaluation. Moreover, in the case of several texture images, understandability dominated the evaluation of complexity. In other words, humans' prior knowledge and experience appear to have a significant effect on visual perception of the complexity of texture images.

This investigation contributes to the identification of the perceptual characteristics of textures that affect visual complexity perception. However, the types of texture images used to investigate visual perception were limited in our experiments. More heterogeneous textures will be used in subsequent experiments.

In the future, we will investigate the objective measures of texture complexity by using image processing, mathematical morphology, and information theory.

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