Morphological Texture Manipulation for The Evaluation of Human Visual Sensibility

Chie Muraki ASANO*, Akira ASANO**, Liang LI** and Takako FUJIMOTO***

* Department of Lifestyle Design, Yasuda Women's University, Yasuhigashi 6-13-1, Asaminamiku, Hiroshima 731-0153, Japan
** Department of Information engineering, Hiroshima University, Kagamiyama 1-7-1, Higashi-Hiroshima 739-8521, Japan
*** Textile Material Laboratory, Hokkaido Univ. Education, Ainosato 5-3-1-5, Kitaku, Sapporo 002-8502, Japan

Abstract: Since the surface texture of materials often affects human visual impressions as much as or more than the design, shape, or color properties, texture characteristics have been studied as features of object identification. We have been investigating the effect of texture on visual impression and objective identification using black fabrics that do not exhibit any effects of color. Our studies showed that visual impressions of texture correspond to complex micro-components and global structures of image features of those textures. Our results also showed that some important elements influence human visual impressions and identification of textures. Because of a variety of fibrous structures, it is not easy to provide a systematic analysis of clothing materials. Nevertheless, developing the method and collecting data on these elements and their effects using these image features will be important. To make this research applicable for wider use, we have been studying precisely what it is about an arbitrary texture that influences human visual impressions and sensibility. As a new step, in this paper, a texture is altered and transformed using the parameter estimation method of texture based on mathematical morphology, which is often used for extracting image components that are useful for representation and description. A texture is decomposed into a primitive and grain arrangement which correspond to local and global characteristics, respectively. Different textures are created by modifying the primitive and the arrangement to investigate the effects of modifications of local and global features. The relationship between the parameters and visual impressions of the modified textures were evaluated. This study shows that influence of both local and global structures of the texture along with their combinations and mutual interactions are important for identification of human visual impression.

Keywords: Kansei, Texture, Mathematical Morphology, Visual Impression, Sensory Test

1. INTRODUCTION

Texture is very important to overall quality of various materials. It affects visual impressions as much as or more than aesthetic properties such as pattern design, color, and shape. Accordingly, the quantitative analysis of features of several typical textures and psychological analysis of human sensitivity to and feelings about textures have been studied [1-9]. In the conventional researches, textures that have a limited number of definable features were used for quantitative analysis. However, human feelings were sometimes psychologically influenced due to use of subjective evaluation language. These limitations made it difficult to apply this research to various wide-ranging textures, and the psychological methods were difficult to apply using evaluations that did not distinctly identify into contrasting results.

Recently, image science and technology have developed remarkably, enabling the reproduction of more delicate images of the texture of materials. It also reproduces human feelings about the materials, whose textures are important in estimating human visual impressions. In fact, systems for evaluating the human sensibility, or “Kansei,” to textures have recently attracted much attention. In particular, objective and qualitative evaluation systems for textures have been required. Therefore, we have been investigating the objective features of textures for explaining human cognition and identification of materials by their visual impressions [10-13].

As part of the investigation, the relationships between several visual impressions of the textural characteristics and image features of some materials have been examined. Effective image features that relate to human visual identification of those textures have also been explored from the viewpoint of Kansei engineering. In those studies, black fabrics were mainly used as samples because of the following two advantages: Black materials allow us to investigate the impressions of texture independent of color, which strongly affects human visual impressions. Fabrics also have fibrous and textural structures that produce subtle differences in visual impression even in two different fabrics of equivalent blackness. These structures enable us to investigate complicated impressions of materials. The visual impressions were quantitatively analyzed and characterized using the image features, which were evaluated by edge detection, Fourier transformation, and segment clustering. These results showed that complex micro-components and global structures of materials as well as their combinations and mutual interactions have a significant influence on human cognition and identification by visual impressions.

However, thus far, it has been difficult to systematically analyze which element produces what effect using these image features. To make our previous research applicable for wider use, we planned to extend our target from exist-
ing specific natural textures to arbitrary ones.

Conventional methods [1-9] of exploring textural features also employ existing natural textures, collected from databases like [14], as target images. In addition, we propose a method of evaluating the effects of the modification of local and global textural features explicitly, contrarily to conventional methods based on Fourier transform or wavelet coefficients [5, 15, 16]. This analysis is realized by the Primitive, Grain, and Point Configuration (PGPC) texture model [17, 18], which enables a separate estimation of local and global features of textures, based on mathematical morphology [19-22].

We utilize this method for the analysis of the relationship between human visual Kansei and local/global features separately. The human visual Kansei on the global features of textures has been already investigated using Fourier transform in [23]; Our method enables to obtain more detailed results on local as well as global features.

This study shows the following: when a texture’s global structure is strongly regular, it strongly affects human visual impressions, but the effects of a texture’s local structure on visual impressions vary with the strength of the regularity of global structure. Moreover, when the global structure’s regularity is weaker, local structures that influence the structuring element and the size and density of the element become more important than the global structure.

2. METHODS

We apply an image processing method based on mathematical morphology to describe a texture by local and global characteristics separately. This method also enables us to modify an arbitrary texture based on each characteristic independently, and to investigate the effect of textural manipulation on human visual identification and impression.

2.1 Mathematical Morphology and Morphological Skeleton

Mathematical morphology is a fundamental framework of image manipulation, and the morphological operations quantitatively manipulate the effect on shape of figures in an image using a small object called structuring element. In the context of mathematical morphology, an image object is defined by a set. When we restrict ourselves to operations on binary images, this set contains the positions of pixels composing the object, i.e. those of white pixels. The structuring element is defined in the same manner. It is equivalent to the window of an image processing filter and is supposed to have much smaller extent than the image object.

The morphological skeleton plays an important role in our work. The skeleton is the extraction of the medial axis in an image object. Let \( X \) be an image set, and \( B \) be a structuring element. The skeleton \( SK(X, B) \) is defined as follows:

\[
SK(X, B) = \bigcup_{n=0}^{\infty} SK_n(X, B),
\]

\[
SK_n(X, B) = (X \Theta nB) \setminus (X \Theta nB)_B,
\]

where \( \Theta \) denotes Minkowski set subtraction, defined as

\[
\Theta = \{ x \mid \exists y \in B, y \subseteq x \},
\]

\( \setminus \) denotes the symmetrical set of \( B \) with respect to the origin, defined as

\[
\setminus = \{-b \mid b \in B\},
\]

\( nB \) is the \( n \)-times homothetic magnification of \( B \) defined as

\[
nB = B \oplus C \oplus \ldots \oplus C \ (\text{with} \ (n-1) \text{-times of } \oplus),
\]

\( 0B = 0 \) (origin).

\( C \) is another small structuring element, as shown in Fig. 1. Note that the usual definition of magnification uses \( B \) itself instead of \( C \). Our definition is different from the usual one, however, we employ this definition to avoid situations where the difference between \( nB \) and \( (n+1)B \) is too large for large \( B \) in the original definition. \( X_b \) denotes the opening of \( X \) by \( B \), defined as

\[
X_b = (X \Theta B) \setminus B.
\]

where \( \oplus \) denotes Minkowski set addition, defined as

\[
X \oplus B = \bigcup_{b \in B} X_b.
\]

Figure 1: (a) structuring element C. (b) structuring element B. (c) structuring element 2B, derived from one-time homothetic magnification of B by a small structuring element C.
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It follows from Eq. (2) that the original image object is reconstructed by locating \( nB \) on every pixel within \( SK_n(X, B) \) and calculating the union for all \( n \), i.e.

\[
X = \bigcup_{n=0}^{\infty} S_k(X, B) \oplus nB .
\] (9)

2.2 Texture Model and Texture Modification

We have proposed a texture expression model called the Primitive, Grain, and Point Configuration (PGPC) texture model [18, 19], which considers a texture as a repetitive arrangement of grains derived from one or a few representative object called primitive. The shape of the homothetic magnification of primitive, the size distribution, and the arrangement are simultaneously estimated by the optimization process automatically.

The PGPC texture model represents a texture image \( X \) as

\[
X = \bigcup_{n=0}^{\infty} B_n \oplus \Phi_n
\] (10)

for nonempty \( \Phi_n \), where \( B_n \) denotes a grain, and \( \Phi_n \) is a set indicating pixel positions to locate grain \( nB \).

We assume here that \( \{0B, 1B, ..., nB, ...\} \) are homothetic magnifications of a small object \( B \) as defined in Eqs.(5) and (6), and that \( B_n \) in Eq.(10) is equivalent to \( nB \) for each \( n \). In this case, \( B \) is regarded as the primitive; \( n \) is referred to as the size of the magnification, and \( X_{ab} \) is regarded as the texture image composed of the arrangement of \( nB \) only. Also \( SK_n(X, B) \) is regarded as the arrangement \( \Phi_n \).

According to [18], the optimum primitive can be estimated by finding the structuring element that minimizes the integral of the size distribution function [19] of a target image, since the residual parts that cannot be covered with the arranged structuring elements are minimized. Once the primitive \( B \) is estimated, the estimate of \( \Phi_n \) is obtained by the morphological skeleton employing \( B \) as the structuring element, because of the equivalence between Eqs. (9) and (10). The set \( \Phi_n \) represents the location of grains of size \( n \). An example of binary primitive and morphological skeletons of different size distributions is shown in Fig. 2 with the original texture.

We can generate new textures from the originals by modifying the primitives and skeletons of each size. A texture can be reconstructed when the primitive and the grain of homothetic expansion are assigned to the skeleton; i.e., another texture can be constructed if each parameter allows arbitrary modification. Figure 3 shows an example of generating a new texture by locating original grains on new skeletons, which are derived from a random distribution. We can regard the generated texture as the union of several layers of each size. More textures can be generated by applying different primitives or skeleton modifications on each layer.

3. EXPERIMENTAL FRAMEWORK

3.1 Texture Manipulation

We have been considering that the estimated primitive or grain of texture shows local features, and the skeleton of texture and the grain size distribution show global
To investigate and describe the effect of texture characteristics on human visual identification and impressions, we experimented on binarized textures with the following procedure:

1. Three different types of texture images were chosen, considering the effects of global regularity.
2. The above-mentioned parameters were extracted from each texture by our proposed method.
3. Those parameters were modified by the following basic manipulations:
   i. Replacing the primitive
   ii. Replacing the size distribution of grains
   iii. Replacing or altering the skeletons
4. The manipulations (i)-(iiii) were combined to vary in the effect of textural modification.
5. Six kinds of structural manipulations, as shown in the caption of Fig. 5, were chosen for this experiment; That is, in the case of (b) and (c), the original primitives of the original images were each replaced with other ones whereas the morphological skeleton and size distribution were preserved while only the elements of size 0 were removed in (a). In (d), (e), and (f), the texture images were constructed by preserving the original primitives and replacing the skeleton with other configurations.
6. Eighteen texture images in total were constructed as shown in Fig. 5.

3.2 Visual Evaluation

The manipulated images were arranged at random as shown in Fig. 6.

Respondents, who had no information on the original images, classified these images into arbitrary groups while evaluating and discriminating the similarity levels of the arranged images.

The subjective visual evaluation and discrimination were performed by more than 40 respondents who have interests in Kansei engineering including participants of the JSKE annual conference.

4. RESULTS AND DISCUSSION

The results of the presented texture images shown in Fig. 6, which were identified, classified, and commented on by the respondents, are summarized in Table 1. The main part of Table 1 is the cross table indicating the number of respondents who combined each pair of two images. The “Number of combination” part indicates the distribution of respondents who made a combination of each number of images. Noteworthy classified combinations of textures from the table are shown in Table 2. In addition, identifiers relating the texture images to those in Figs. 5 and 6 are also shown in Table 2. The result of classification in the table consistently indicates a remarkable influence of the oblique effect and the effect of uniform repetition, as in conventional studies, whereas other textures which have complex structures were not influenced by those properties.

Based on the symbols of the textures listed as (a), (b), and (c) in Fig. 5, the results of visual classification for the modified textures indicates the following: When a texture includes a lot of large grains, the density and regularity of the morphological skeleton affect visual impressions. For example, modified textures of (III) tendentially classified into the same group as the original image, while (I) depended on the primitive shape. The visual impressions of texture images consisting of smaller grains and high-density skeleton, such as texture (II), varied very little from the impression of the original texture. However, the impressions of the textures were well distributed by the respondents. When textures (d), (e), and (f) in Fig. 5 were modified to investigate the effect of randomization of the regular skeleton, the impression definitely varied when the regularity of the skeleton was clearly changed.
Comparing the results with the visual evaluation, the visual impressions of texture varied when the configuration of grains whose size has a wide distribution in the texture was manipulated, especially in the case of an original skeleton of low density.

We also investigated which features/characteristics of textures were evaluated and observed during classification by the visual impressions of respondents, as shown in Table 2. When the subjects observed a texture with clearly uniform direction such as the diagonal, they recognized a stronger impression from the configuration of the morphological skeleton than from the primitive. Otherwise, in the case of textures whose skeleton was configured in an unclear direction, human subjects paid more attention to the impression of primitive shapes such as granulation, fluff, or prickle.

In this investigation, the number of groups classified by subjects varied since no limitation was placed on it during the visual evaluations. Therefore, the typical texture groups classified by most respondents were investigated.
It will be necessary to consider standardization in the number of groups and the range of the number of textures in one set of experiments in the future. It would also be necessary to consider the criterion of classifications according to the textural property focused on for an investigation. Furthermore, those methods and criterion would be applied to other textures, including grayscale ones, to obtain more precise observations.

Table 1: Respondents ratio at the combinations of textures (%).

<table>
<thead>
<tr>
<th>Texture identifiers (shown in Figure 6)</th>
<th>Number of combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) - 19 24 19 24 24 24</td>
<td>57 19 24</td>
</tr>
<tr>
<td>(2) 19 - 100</td>
<td>81 19</td>
</tr>
<tr>
<td>(3) - - 100</td>
<td>3 3 83 17 80 3</td>
</tr>
<tr>
<td>(4) 24 - - 100</td>
<td>1 75 24</td>
</tr>
<tr>
<td>(5) 19 100 -</td>
<td>81 19</td>
</tr>
<tr>
<td>(6) - - 100</td>
<td>27 18 61 21</td>
</tr>
<tr>
<td>(7) 24 99 -</td>
<td>99 1 75 24</td>
</tr>
<tr>
<td>(8) - - 100</td>
<td>9 27 14 59</td>
</tr>
<tr>
<td>(9) 100 -</td>
<td>3 3 83 17 80 3</td>
</tr>
<tr>
<td>(10) 100 -</td>
<td>59 59 9 27 14 59</td>
</tr>
<tr>
<td>(11) 100 -</td>
<td>61 27 18 61 21</td>
</tr>
<tr>
<td>(12) 24 100 99</td>
<td>- 1 75 24</td>
</tr>
<tr>
<td>(13) 89 -</td>
<td>61 - 39 18 61 21</td>
</tr>
<tr>
<td>(14) -</td>
<td>2 98 2</td>
</tr>
<tr>
<td>(15) 3 59 3 59</td>
<td>- 100 20 21 17 59 3</td>
</tr>
<tr>
<td>(16) 3 59 3 59</td>
<td>100 - 20 21 17 59 3</td>
</tr>
<tr>
<td>(17) 83 83</td>
<td>20 20 - 97 3</td>
</tr>
<tr>
<td>(18) 27 9 9 27 39 2 -</td>
<td>45 20 14 21</td>
</tr>
</tbody>
</table>

Table 2: Typical results of classification of manipulated texture images by subjective visual experiment.

<table>
<thead>
<tr>
<th>No.</th>
<th>Combination of classified textures</th>
<th>Texture identifiers in Fig. 6</th>
<th>Texture identifiers in Fig. 5</th>
<th>Respondents ratio</th>
<th>Noticed feature (Respondents’ remarks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1.png" alt="Image" /> <img src="image2.png" alt="Image" /></td>
<td>(2)-(5) III(e)-III(f)</td>
<td>81%</td>
<td>Granulate</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td><img src="image3.png" alt="Image" /> <img src="image4.png" alt="Image" /> <img src="image5.png" alt="Image" /></td>
<td>(3)-(9)-(17) I(b)-I(a)-I(d)</td>
<td>80%</td>
<td>Stripe Slanting</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td><img src="image6.png" alt="Image" /> <img src="image7.png" alt="Image" /> <img src="image8.png" alt="Image" /></td>
<td>(4)-(7)-(12) III(b)-III(c)-III(a)</td>
<td>75%</td>
<td>Hole Regularity</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td><img src="image9.png" alt="Image" /> <img src="image10.png" alt="Image" /> <img src="image11.png" alt="Image" /></td>
<td>(6)-(11)-(13) II(a)-II(d)-II(b)</td>
<td>62%</td>
<td>Fluff</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td><img src="image12.png" alt="Image" /> <img src="image13.png" alt="Image" /> <img src="image14.png" alt="Image" /></td>
<td>(8)-(10)-(15)-(16) II(c)-II(f)-II(c)-II(f)</td>
<td>59%</td>
<td>Suspicious</td>
<td></td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

We have been interested in finding out which features or characteristics of an arbitrary texture influence human impressions and sensibility, and we have proposed a method for analyzing which element produces what effect by image processing. We found that not only the individual influences of local and global structures of the texture,
but also their mutual interactions, are important.

This paper proposed a new systematic analysis method based on mathematical morphology for human visual impressions of arbitrary textures. The number of textures chosen for the experiment was only three, since this study was just the first stage for our proposed method. However, it was shown that the modified textures varied with the method used, and that these textures could provide different impressions even if the number of original textures was this small. As a result, important information of visual sensibility was derived from this experiment.

We are applying this method to the modification of grayscale textures at present for comparison with quantitative classification results using our analysis method with the previous image features, and to explore its extended usage [25]. Furthermore, to analyze our results more precisely, we consider collecting much more texture data in order to apply multivariate analysis to the data in the future. These researches will also be practically applied to the innovation of textile resources in our future works.

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Chie Muraki ASANO
Chie Muraki Asano is an Assistant Professor of the Department of Lifestyle Design, Yasuda Women’s University, Japan. From 1997 to 2002, she was an Assistant Professor of the Department of Biosphere-Geosphere System Science, Okayama University of Science, Japan. Her current research interests are in the areas of kansei science related with textile and apparel science. She is a member of Japan Society of Kansei Engineering, Japan Society of Home Economics, the Information Processing Society of Japan, the Japan Statistical Society, and Japanese Society of Applied Statistics.

Akira ASANO
Akira Asano is a Professor of the Department of Information Engineering, Graduate School of Engineering, Hiroshima University, Japan. He became a research associate of the Department of Mechanical System Engineering, Kyushu Institute of Technology, Japan, in 1992. He moved to Hiroshima University in 1998, and was promoted to a Professor in 2005. His current research interests are in the areas of mathematical morphology, medical image analysis, visual kansei science, and applied statistics. He is an Associate Editor of the IEICE Transactions on Fundamentals of Electronics, Communications, and Computer Sciences, and a member of Japan Society of Kansei Engineering, Japanese Society of Applied Statistics, and IEEE. http://laskin.mis.hiroshima-u.ac.jp/

Liang LI
Liang Li received the BEng degree from Taiyuan University of Technology, China, in 2005, and received the MEng degree in information engineering from Hiroshima University, Japan, in 2008. He is pursuing the DEng degree in information engineering at Hiroshima University, Japan. His research interests include Kansei engineering, mathematical morphology, texture analysis, and pattern recognition.

Takako FUJIMOTO
Takako Fujimoto is a Professor at the Laboratory of Apparel Material Science and Kansei Engineering, Sapporo Campus, Hokkaido University of Education since 1995. She was a visiting professor of the New South Wales University of Australia for seven months in 1996-1997. She has extensive capability and expertise in testing mechanical and comfort-related properties of fabrics, and a considerable amount of research on those properties has been published. She has recently developed unique instruments to detect kansei-related properties of fabrics. She is a member of the Textile Machinery Society of Japan, the Japan Research Association for Textile End-uses, the Society of Fiber Science and Technology Japan and Japan Society of Home Economics. She has also been a member of the Textile Institute (UK) since 1981, and served as the Chairperson of Japan Section of the Textile Institute, 2005-2010.