The Realistic Texture Reconstruction on Display

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Abstract

Image texture is defined as a function of the spatial variation in pixel intensities and has been a subject of intense study by many researchers. In the conventional methods of enhancing texture reproduction, only the lightness component is usually considered and different characteristics classified by texture category are not considered.

In this study, we investigate the emotional adjectives related with visual tactility and texture. They are classified into three categories which can typically stand for Rough, Glossy and Soft texture. For visual tactility, texture is reproduced by both lightness enhancement based on lightness information and on the colour enhancement based on colour properties in each texture category.

The purpose of this study is to investigate the relationship between visual tactility and colour property. Following this relationship, we propose a realistic texture reproduction method for different texture types.

Introduction

Texture is an important cue in human visual perception and it plays an important role in image processing and computer graphics [3][4]. Texture provides information on the depth and orientation of an object as well as the reality of object in large displays. The surface details become more delicate as the resolution increases and higher resolution is required for realistic image representation in large displays. Hence, realistic texture reproduction in large displays is extremely important.

Usually, texture is defined as a function of the spatial variation in pixel intensities. The visual properties of texture are classified into colour and lightness properties and these two properties have a high correlation. A small variation of surface lightness would cause substantial changes in the perception of the color properties, while the surface geometry represented by lightness would be recognized differently depending on the variation of the colour property. In other words, the visual tactility, which is a broader concept than the texture, means the tactile sense derived from the lightness property from surface texture and the colour property from light. There have been many studies about texture reproduction and previous studies focusing on texture reproduction only dealt with lightness components without considering color property according to texture type. In these cases the images are processed collectively without considering the types of texture and hence the visual tactility decreases significantly.

In this paper, a realistic texture reproduction algorithm based on the control of colour and lightness attribute are proposed. This study tries to find out the interesting change of tendency in visual tactility according to the colour attribute and psychophysical experiments were conducted to derive colour attributes for each texture categories. Also, the performances of the developed method are compared with conventional one by emotional adjectives.

The rest of the paper is organized as follows. In the next section, the psychophysical experiment for deriving color and lightness properties according to texture category are explained and the color control methods for realistic texture reconstruction are proposed. Finally, the last section presents experimental results and conclusion.

Psychophysical Experiment 1 - Derive Colour Main Factors

In this study, the texture is classified into rough, glossy and soft. These three different textures are the most typical and distinctive emotional adjectives related with the visual tactility from the existing research data and these were selected as the representative of texture category [5].

The experiment was performed in a dark room using the characterized standard monitor (BARCO). Figure 1 represents the colour gamut and tone characteristics of the monitor used in the experiment. The monitor had a colour gamut similar to sRGB and the gamma value of the tone curve was 2.3. The monitor also had a good additivity.

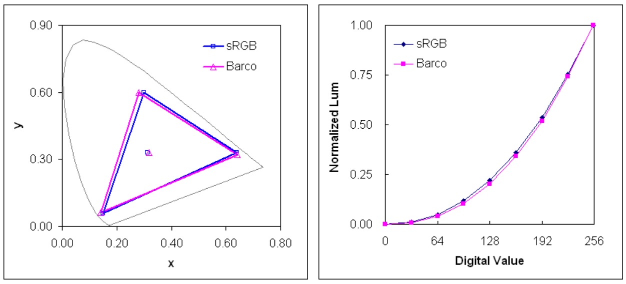

***Figure 1.** Characteristics of the Barco monitor used in the experiment, (left) tone curve, (right) colour gamut*

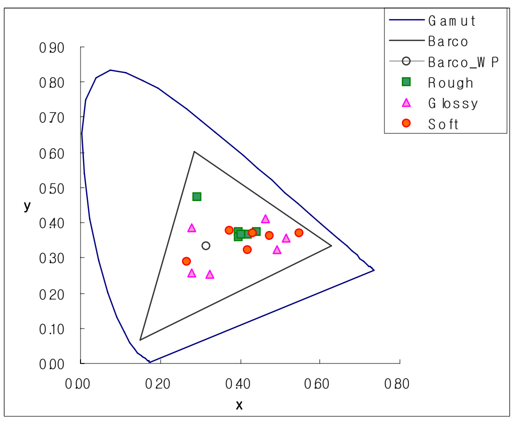

***Figure 2.** Distribution of the average value of test images (Experiment 1)*

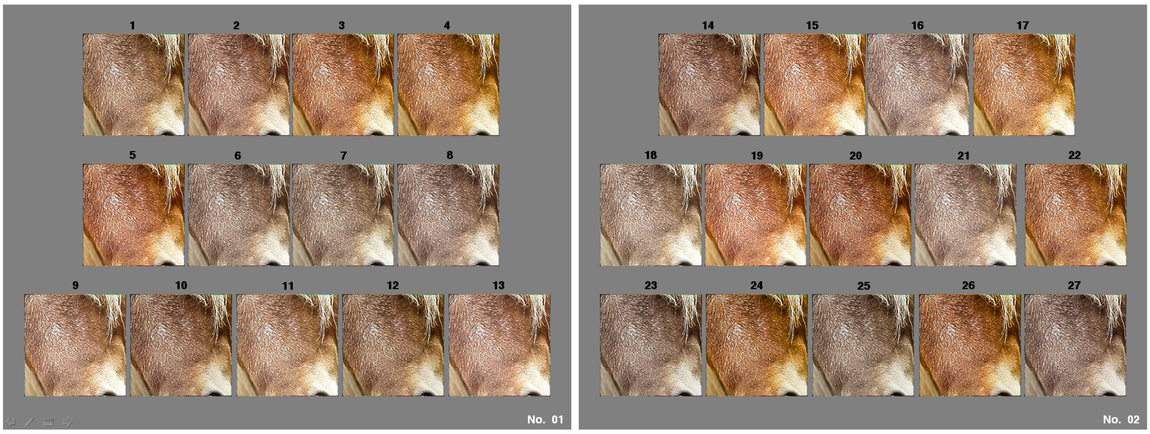

Figure 3. Experimental test patterns for rough texture

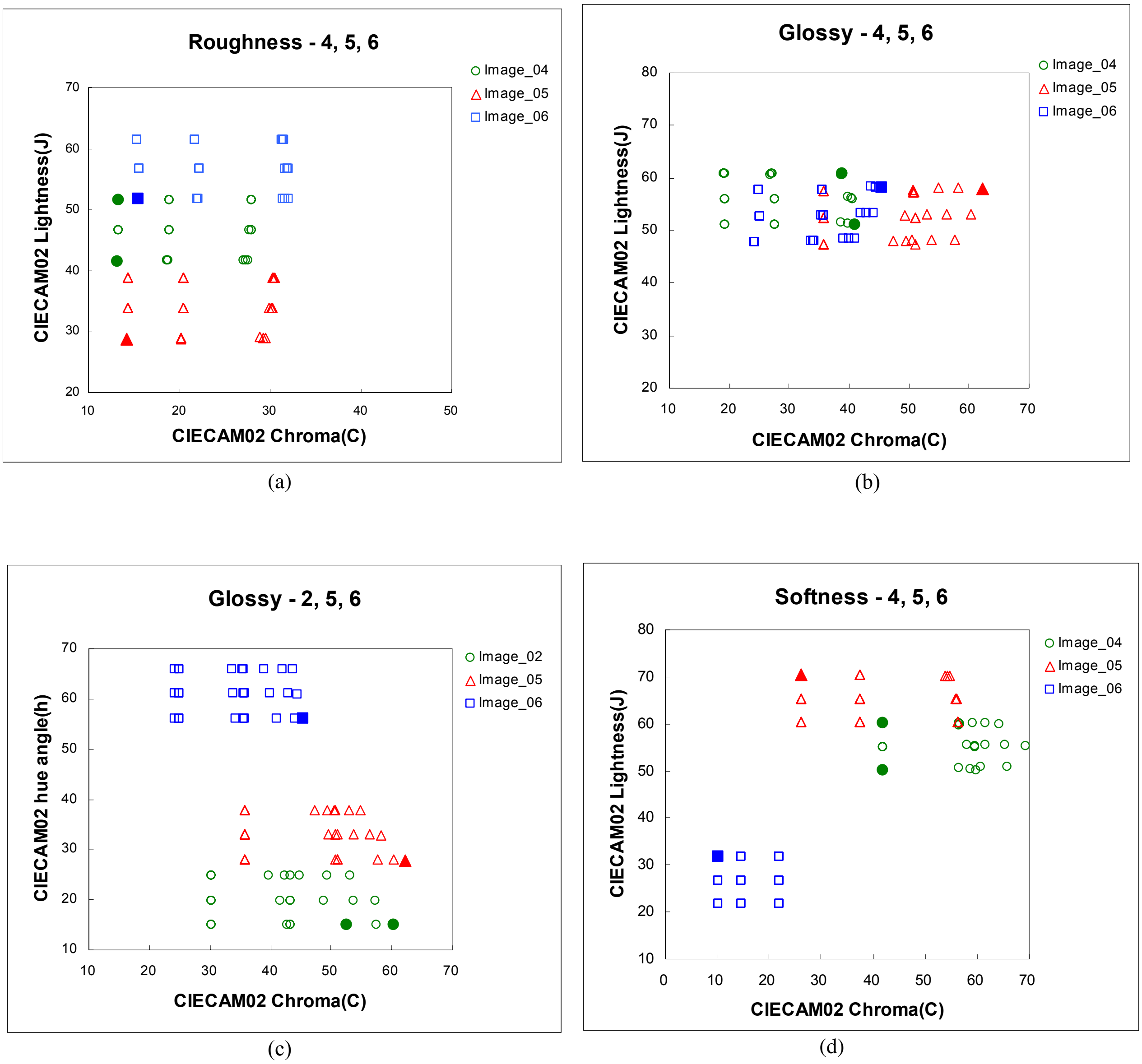

Figure 4. CiECAM02 lightness, chroma and hue angle of the average of the test images (filled symbol: the most rough, glossy and soft)

This experiment is to find main colour attributes for realistic texture reproduction in each representative texture category; rough, glossy and soft. During the experiment, observers were asked to select an image which gave the more emotional feeling for each texture category among several test images shown in monitor. Figure 3 shows the example of test images used in the psychophysical experiment. The size of the images were adjusted to 5.3cm(W)x5.3cm(H) (•2.99", diagonal) and 6 images are used for each texture category (that is, total 18 images were used). The distance between screen and observer was recommended to be 30 to 40 cm but observers are allowed to move their position. All observers participated in the experiment passed the Ishihara test and they understood the definition of the adjectives (rough, glossy and soft) before performing the assessments.

At first, the R, G, B values of the input images are converted into the CIECAM02 colour space. The converted J (Lightness), C (Chroma), H (Hue) of CIECAM02 are controlled by 3 steps ($-\Delta$, 0, $+\Delta$). Thus 27 pairs were compared for each image and the observers selected the image which is the closest to the emotional adjectives (rough, glossy and soft) out of the images presented on the monitor. The experiment was performed two times repeatedly and for each experiment, the images were randomly displayed to each observer.

Figure 4 depicts CIECAM02 average chroma, lightness and hue of some transformed images. The filled symbols represent the roughest, glossiest and softest images among selected ones. The most noticeable feature in Figure 4 (a) is that the roughest image has the lowest C and J values. In case of rough texture, decreased J and C values are enhancing the visual tactility and H value doesn't have an effect on the texture representation. In case of soft texture, the increased J value and decreased C value are enhancing the visual tactility and H value which is changed to the opposite direction of unique hue is enhancing the visual tactility. The values of unique hue for each colour range is as follows; Red is 20.14 and 380.14, Yellow is 90, Green is 164.25 and Blue is 237. 54.

Figure 4 (b) shows the relationship between lightness and chroma factors for glossy texture and Figure 4 (c) shows the relationship between hue angle and chroma for glossy texture. For glossy texture, increased J/C values and hue angle moved to the direction of unique hue have an effect on glossy texture.

Table 1 shows frequency result for each texture category and the overall colour factors derived in this experiment are summarized in Table 2.

Table 1. The experiment result for frequency of texture category

No	Gain-J	Gain-C	Gain-h	Rough-Freq.	Glossy-Freq.	Soft-Freq.
1	0	1	5	0	0	1
2	0	1	-5	1	0	0
3	0	1.5	0	0	0	1
4	0	1.5	5	0	1	0
5	0	1.5	-5	0	1	1
6	0	0.7	0	2	0	3
7	0	0.7	5	6	0	4
8	0	0.7	-5	1	0	4
9	5	1	0	1	2	4
10	-5	1	0	2	3	1
11	5	1	5	0	1	4
12	-5	1	5	0	1	0
13	5	1	-5	0	1	3
14	-5	1	-5	0	1	0
15	5	1.5	0	0	4	5
16	-5	1.5	0	1	0	0
17	5	1.5	5	1	4	4
18	-5	1.5	5	0	3	0
19	5	1.5	-5	0	**30**	2
20	-5	1.5	-5	1	3	0
21	5	0.7	0	7	2	8
22	-5	0.7	0	14	0	0
23	5	0.7	5	1	1	11
24	-5	0.7	5	7	0	0
25	5	0.7	-5	6	0	4
26	-5	0.7	-5	9	2	0

Table 2. Result of derive colour main factor experiment

	Rough	Glossy	Soft
J	Decrease	Increase	Increase
C	Decrease	Increase	Decrease
h	-	Unique hue direction	Far from Unique hue direction

Realistic Texture Reconstruction Algorithm

The main purpose of this study provide a texture reproduction algorithm maximizing realism by controlling both a lightness attribute and a color attribute, which configure a tactile sensation of a visual aspect.

The proposed texture reconstruction algorithm consists of lightness, chroma and hue correction unit. The function of each correction unit is based on previous psychophysical experiment and correction method of each unit is differently designed.

Lightness Rescale Unit

If the lightness is linearly controlled in accordance with psychophysical experiment result of each texture category, the global contrast of result image is severely reduced. To prevent this problem and reflect the effect of psychophysical experiment result, the sigmoid function is used in lightness correction process and the different gains are applied in accordance with texture category.

The sigmoid function is based on a phenomenon of simultaneous lightness contrast, which is to make dark colors looks darker by making light colors looks lighter. The sigmoid function may be controlled by two factors x_0 and a sigma as described in Equation 1. The proposed method uses the average lightness as x_0.

$$S_i = \sum_{n=0}^{n=m} \frac{1}{\sqrt{2\pi}\sigma} e^{-((100x_n/m - x_0)^2/2\sigma^2)}$$

$$S_{LUT} = \frac{(S_i - \min(S))}{(\max(S) - \min(S))} \times (J_{\text{maxout}} - J_{\text{minout}}) + J_{\text{minout}} \tag{1}$$

Where S_i denotes a cumulative standard normal distribution of an average x_0 and a standard deviation σ, and m denotes a maximum lightness value. S_{LUT} is the lightness remapping LUT. The x_0 controls the centering of the sigmoid and σ controls the slope. As the σ is decreased, the remapping function increases the image contrast by boosting the slope in the midtones while equally compressing the highlight and the dark tones.

As we described above, the realistic texture reproduction algorithm may apply different gains to the texture as the rough, glossy and soft based on the average value.

Figure 5 illustrates an example of a lightness remapping curve for the glossy and soft textures after applying a sigmoid function in accordance with psychophysical experimental result. Specifically, a curve (b) shows the contrast enhanced curve by sigmoid function and curve (a) illustrates a lightness correction tone curve based on curve (b). As shown in Figure 5, comparing with base tone curve for preventing contrast reduction by lightness remapping, the lightness value is increased centering the average lightness value (c).

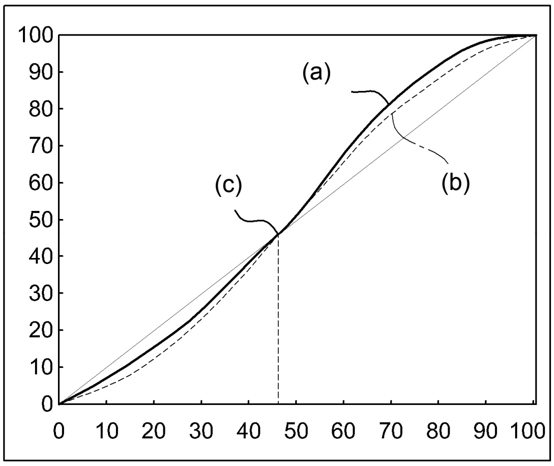

Figure 5. Illustrates an example for describing a lightness remapping for the soft texture after applying a sigmoid function

Conversely, the lightness should be decreased centering the average lightness value in case of rough texture. To accomplish the lightness remapping with sigmoid function for all texture categories, following equation are used.

$$\begin{aligned} &if (J \le J_{avg}) \quad J = S_{LUT}[J] + (J_{Linear} - S_{LUT}[J]) \times Gain_{down} \\ &else \quad\quad\quad J = S_{LUT}[J] - (J_{Linear} - S_{LUT}[J]) \times Gain_{up} \end{aligned} \tag{2}$$

Where J denotes a lightness value, J_{avg} denotes an average value, $S_{LUT}[J]$ denotes a lightness remapping LUT and J_{Linear} denotes a linear mapped lightness value. Also, $Gain_{down}$ and $Gain_{up}$ denote a gain for low lightness region and high lightness region, respectively. By controlling $Gain_{down}$ and $Gain_{up,}$ the tone curve can be generated adaptively for all texture categories.

Hue Correction Unit

As summarized in Table 2, the hue change with reference to unique hue has an effect on visual tactility in case of glossy and soft texture. The hue correction unit changes an input hue according to the texture type. The basic operation of hue correction is to move an input hue adaptively based on a distance between an input hue and a target hue for each hue quadrature. The hue quadrature of CIECAM02 may be configured from 0 to 400, and include Red (0 to 100), Yellow (101 to 200), Green (201 to 300), and Blue (301 to 400). The target hue in each hue quadrature according to texture type is shown in Table 3. As shown in Table 3, the target hue in glossy texture is the same direction of unique hue in each hue quadrature and in soft texture, the target hue is opposite direction of unique hue.

Table 3. The target hue for each texture category

	Rough	Glossy	Soft
0 ~ 100	-	1	99
101 ~ 200	-	199	102
201 ~ 300	-	299	202
301 ~ 400	-	399	302

The hue correction unit verifies hue quadrature of the input hue, and moves the hue in the direction of the target point predetermined in the corresponding hue quadrature based on the distance in accordance with Equation 3.

$$\begin{aligned} &if \;\; H_{in} < H_{target} \\ &H_{out} = H_{target} - (H_{target} - H_{in})^2 \cdot \frac{s}{H_{range}} - (1-s)\cdot(H_{target} - H_{in}) \\ &if \;\; H_{in} > H_{target} \\ &H_{out} = H_{target} + (H_{target} - H_{in})^2 \cdot \frac{s}{H_{range}} + (1-s)\cdot(H_{in} - H_{target}) \end{aligned} \tag{3}$$

Where s means the strength of hue change and it is a parameter denoting a conversion degree of a hue. The range of s is between 0 and 1. Also, H_{range} denotes a hue division range dividing entire hue values ranging from 0 to 400 by four areas. H_{in} denotes input hue, H_{target} denotes a target hue, and H_{out} denotes a corrected value.

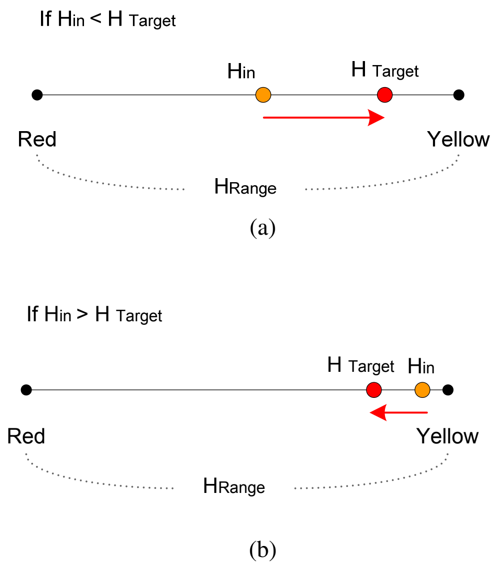

***Figure 6.** 6(a) and 6(b) illustrate an example for describing a hue movement method.*

Chroma Correction Unit

The chroma correction unit controls the chroma component linearly based on chroma characteristics derived from psychophysical experiment. In the chroma correction unit, a linear function in accordance with Equation 4 may be used for increasing or decreasing the chroma for each texture category. In Equation 4, $Chroma_{out}$ and $Chroma_{in}$ respectively denote an input and an output chroma, and $Gain_{chroma}$ denotes a cotnrol gain for each texture characteristic.

$$Chroma_{out} = Gain_{chroma} \times Chroma_{in} \quad (4)$$

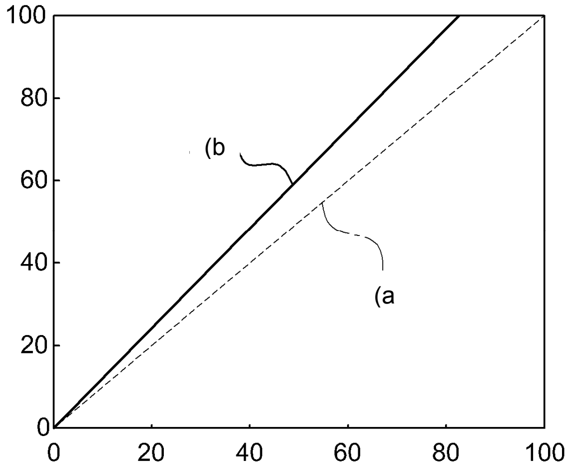

Figure 7. Illustrates an example for describing a chroma enhancement or decrement for the texture category

FIG. 7 illustrates the example of chroma correction. X-axis illustrates an input chroma and Y-axis illustrates an output chroma. A dotted straight line (a) means no chroma control and a solid straight line (b) shows the example of the chroma incensement.

Psychophysical Experiment 2 – *Comparison with Conventional Method*

This experiment is to show the distinguished performance difference between the conventional lightness-based texture enhancement method and the proposed realistic texture reconstruction algorithm. The conventional lightness-based texture enhancement method emphasizes the lightness attribute by enhancing high spatial frequency component of lightness component [6].

The experiment environment and conditions are the same as experiment 1 and the paired comparison method is used to evaluate the performance.

A total of 6 test images were selected and 5 observers participated at the experiment. The observer did not know which one is the original and the degree of visual tactility is measured by the likert scale. The likert scale is a bipolar scaling method measuring either positive or negative response to a statement. Each observer is asked to rate each texture type by following scales:

1. Completely not rough/soft/glossy
2. Mildly rough/soft/glossy
3. Moderately rough/soft/glossy
4. Very rough/soft/glossy
5. Extremely rough/soft/glossy

The frequency data for each texture image pair are summarised in Table 4 and Table 5.

The mean of frequency value divided by the total of observations represented the visual tactility difference in an interval scale. This method is called mean-category-value method or category mean.

The category mean of the conventional texture enhancement method was 8.4 and that of the realistic texture reconstruction algorithm was 11.1. As shown in table 6, the proposed texture reconstruction method shows better performance than lightness-based conventional texture enhancement method.

Table 4. Frequency data of the Conventional texture enhancement Method

The Conventional texture enhancement						
Obs-erver	#1	#2	#3	#4	#5	#6
1	3	4	2	4	2	2
2	2	2	2	2	2	2
3	2	2	4	4	3	4
4	4	3	2	3	3	3
5	3	4	2	1	4	4

Table 5. Frequency data of Realistic Texture Reconstruction Method

The Realistic Texture Reconstruction						
Obs-erver	#1	#2	#3	#4	#5	#6
1	4	4	4	3	4	4
2	4	4	4	4	5	5
3	3	3	2	3	2	3
4	5	3	4	5	5	5
5	3	4	3	4	3	2

Table 6. Mean-Category-Value Method Result

	Rough	Glossy	Soft	Category Means
CM	2.9	2.6	2.9	8.4 (Average 2.8)
RTR	3.7	3.6	3.8	11.1(Average 3.7)

Also, the preference test was performed to evaluate the correlation between the visual tactility and preference.

The experimental setup was the same likert scale is used. Each observer answered his own preference between the realistic texture reconstruction images and the corresponding conventional ones.

The result shows that around **72.7%** of the realistic texture reconstruction images were better than the conventional ones. Even though it was a simple test, we could conclude that the preference and visual tactility shows almost the same tendency in the end.

Psychophysical Experiment 3 –The Performance Evaluation of Texture Reproduction algorithm

The purpose of this experiment is to test the performance of the developed methodology. The experiment condition and environments are same as experiment 1 and 2. A total of 30 test images were selected and 10 observers participated at the experiment. During the experiment, each transformed image was compared with the original image by the observers.

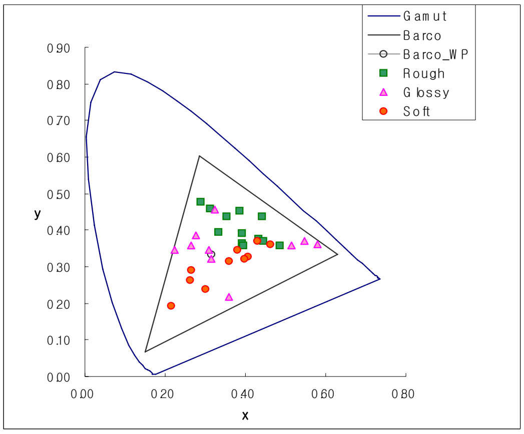

Figure 8. *Distribution of the average value of test images (Experiment 3)*

The observers did not know which ones are the original and the degree of colour combination is measured by the likert scale as well. The test images were chosen such that the average colour values are widely distributed in the colour spaces as shown in Figure 8. The results were calculated using the categorical judgement method and Mean-Category-Value Method for each texture and images.

Table 7. Mean-Category-Value Method Result

	Rough	Glossy	Soft	Total
Original	4.43	3.97	5.60	4.667
RTR	5.99	6.18	6.33	6.167

The category means of the realistic texture reconstruction algorithm was 6.167 and that of original images without any processing was 4.667. In other words, the performances of proposed method for rough and glossy texture are increased to 35.21% and 55.67% respectively and in the case of soft texture, the performance is increased by 13.04%.

Table 8. The Categorical Judgment method Result

	Rough	Glossy	Soft	Total
Original	1.17	1.4	2.0	1.6996
RTR	2.8	3.0	2.5	2.7624

As shown in the table 8, the categorical judgement of the realistic texture reconstruction algorithm was 2.7624 and that of original images without any processing was 1.6996.

Figure 9. *Images for the test (left: original image, right: applied realistic texture reproduction algorithm)*

Result and Conclusions

The realistic texture reconstruction algorithm which consists of the lightness control and the colour control is proposed. Conventionally, unsharp masking and soft blurring techniques for lightness component are widely used to enhance the texture component. However, through several psychophysical experiments, we can prove colour component is highly related to visual tactility and show both lightness and colour control can increase the visual tactility in the reconstruction of texture. As stated above, the characteristics of the texture cannot be represented only by lightness-based texture enhancement alone and colour characteristic control can increase both visual tactility and realism along with lightness texture enhancement.

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