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Visual Perception Characteristics of Surface Unevenness - Focused on Orange Peel Effect -

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Objective: The purpose of this study is to identify visual perception of and satisfaction with the orange peel effect of surface. The orange peel effect is a type of finish on painted or coated surface.

Background: Gloss paint sprayed on a smooth surface (such as car body, smart phone, and electric home appliances, etc.) should also dry into a smooth surface. Then, a surface resembling the texture of an orange peel can be caused by some factors. The orange peel effect can degrade user's satisfaction with a product.

Method: Visual perception and emotional satisfaction were subjectively evaluated using Likert scale. The significance of orange peel effect on visual perception and satisfaction were then analyzed by the analysis of variance. The correlation between visual perception and satisfaction was also analyzed.

Results: Surface roughness significantly influenced visual perception and emotional satisfaction. The level of visual perception increased and emotional satisfaction decreased with the increase of orange peel effect. Emotional satisfaction decreased with the increase of visual perception level.

Conclusion: It was identified that orange peel phenomenon on surface was a very important factor for emotional satisfaction. The orange peel effect on the surface of a product should be minimized to improve the emotional satisfaction of the product.

Application: The result of this study can be applied to the texture design of the body of a car, smart phones, and electric home appliances, etc.

Keywords: Orange peel effect, Surface unevenness, Visual perception, Emotional satisfaction

1. Introduction

The quality of surface treatment for car body, electric home appliances or smartphones is one of the important factors affecting customer satisfaction (Kang, et al., 2000). Buyers of a product judge the quality of the product by looking at and touching the product, when they buy. In doing so, the gloss or texture of the product surface has critical influence on the customer's product selection (Lee, et al., 2000). Burrows (2012) said high gloss and smooth finish are one of the most important factors deciding high quality product. Therefore, if the surface of a product is rough or not even, it negatively affects product purchase, and also negatively affects customer's emotional satisfaction with the product (Kim, 2007). Surface roughness

refers to delicate level of unevenness caused in the process of surface processing, coating or painting. It is impossible to process perfect surface geometrically in reality. Looking at the zoomed-in photo of the processed surface, many curves are confirmed to exist on the surface.

The orange peel phenomenon is the unevenness of surface caused in the process of surface coating and painting (Cao et al., 2005, Burrows, 2012). Minimizing orange peel phenomenon is a very important issue in the surface treatment process. One of the factors discerning luxury cars and non-luxury cars in the auto industry is the status of orange peel effect demonstrated from the body of a car (Konieczny and Meyer, 2011). Because human's vision is very sensitive to the texture effect that is generated by the orange peel phenomenon in the glossy surface, it is necessary to finish work well so that humans do not perceive such a phenomenon (Burrows, 2012).

Therefore, this study was conducted to identify human visual perception characteristics and emotional satisfaction on the orange peel phenomenon of surface that has an important impact on the surface texture of a product.

2. Surface Roughness of Product

The product surface is made by raw materials and surface treatment covering the raw materials. Such surface treatment has a purpose to expand the physical and chemical limits of raw materials, or psychological or aesthetic function, beyond the meaning of simply packing the exterior of raw materials, (Kim, 2007). The product surface roughness is caused in the process of raw materials processing or surface treatment process including painting or coating. Surface roughness negatively affects consumer satisfaction.

The roughness of the product surface is fine curves with small gap on the surface, and the curve's size and shape are different, according to processing or surface treatment mode. Surface treatment is complicatedly composed of various types of roughness, and therefore, roughness cannot be indicated with a number. Instead, surface roughness is expressed through statistical processing including the mean of amplitude indicating the height of roughness and the mean of roughness gap. The statistical value indicating the level of roughness is called roughness parameter.

The method to demonstrate surface roughness the best is to show by zooming-in delicate surface shape. However, the method has many cumbersome things, such as photographing by zooming-in the surface and reinterpretation of the photo again, and thus, it is inefficient. Therefore, indicating the entire surface roughness with representative value is a general trend.

This study used mean square roughness as the parameter indicating surface roughness, and the mean square roughness is calculated using the method of root-mean-square (rms). Figure 1 shows the mean line of surface roughness, and the mean square roughness demonstrates the root-mean-square of the distance between the mean line and peaks, and valleys indicating roughness (KS B 0161, 1999).

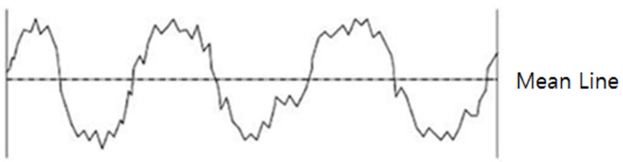

Figure 1. Mean line of surface roughness

One of the important causes of surface roughness is an orange peel effect caused in the process of surface processing, painting and coating. Generally, the evenness of surface texture of cellphone cover, product surface and car body is determined by the uneven phenomenon like an orange peel effect. As shown in Figure 2, fine curve exists on the surface texture in many cases, if the surface is zoomed-in, although the formation is made evenly.

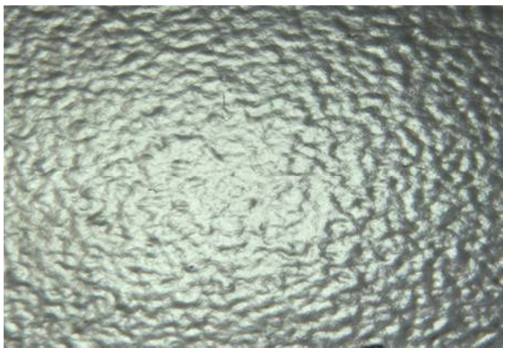

Figure 2. Orange peel effect

Because, the orange peel effect of the surface negatively affects product's surface texture from a visual aspect, it is important to finish the surface not to cause such an orange peel effect. The causes of orange peel demonstrated in the process of surface painting are known as follows: when painting viscosity is high; when thinner's volatility is quick; when spray pressure is insufficient; when spray coating thickness lacks; when spray distance is insufficient.

Although, the orange peel effect caused on the product surface is known to affect a negative effect on the visual surface texture, the clear identification of visual perception level and influence on emotional satisfaction, according to orange peel phenomenon, and correlations between visual perception level and emotional satisfaction has yet to be made. Therefore, study on such issues is meaningful from the surface texture design aspect. To this end, this study analyzed what impacts the orange peel effect have on human visual perception and emotional satisfaction targeting black cellphone cover.

3. Experimental Method

3.1 Experimental material and subjects

This study evaluated visual perception characteristics and emotional satisfaction of the experiment subjects by using ten black samples with different surface roughness. The parameter indicating each sample's surface roughness was mean square roughness, measured by a 3D canner, and the unit of roughness is μm. Table 1 shows the measured values of the mean square roughness of the samples used in the experiment.

Table 1. Experimental materials (unit: μm)

No / Color	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Black	4.01	4.42	4.92	5.19	11.82	12.98	19.77	14.20	14.01	16.90

The subjects who took part in the experiment are 50 people (25 men and 25 women) without visual impairment, and their age and gender distribution are exhibited in Table 2.

Table 2. Subjects

Gender \ Age	~25	25~35	35~
Male	10	10	5
Female	10	10	5

3.2 Evaluation method

The subjects were instructed to evaluate visual perception level and emotional satisfaction on the orange peel effect, after looking at the samples having different surface treatment with a 7-point scale. The following Table 3 and Table 4 are respectively the evaluation scales for emotional satisfaction and visual perception evaluation of the orange peel effect used in the experiment:

Table 3. Evaluation scale for emotional satisfaction

Sample number	Very bad	Quite bad	Somewhat bad	Neither	Somewhat good	Quite good	Very good
	1	2	3	4	5	6	7

Table 4. Evaluation scale for visual perception

Sample number	Very weak	Quite weak	Somewhat weak	Neither	Somewhat strong	Quite strong	Very strong
	1	2	3	4	5	6	7

In the experiment, subjective opinions on what criteria to visually judge surface roughness were used were also collected, in addition to emotional satisfaction and visual perception evaluation on surface treatment. Figure 3 shows experimental scenes.

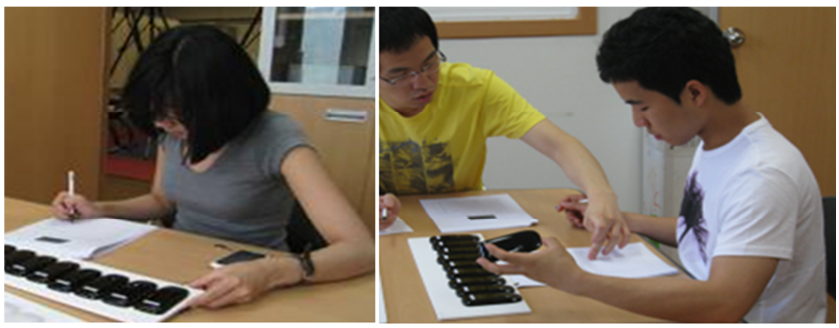

Figure 3. Experimental scene

4. Results

4.1 Visual perception of the orange peel effect of surface

To find out visual perception characteristics of the orange peel effect caused in the process of surface processing or coating process of a sample, this study carried out the variance of analysis (ANOVA), based on subjective evaluation results. According to the analysis results as shown in Table 5, the orange peel effect significantly affected the visual perception level as shown in Table 5 (p=0.00< 0.05)

Table 5. ANOVA for visual perception with orange peel effect

		Sum of square	df	Mean square	F.	Sig.
Perception	Between group	1351.178	9	150.131	125.130	.000
	Within group	587.900	490	1.200		
	Sum	1939.078	499			

Figure 4 shows the relation between visual perception level and orange peel effect. As orange peel level increases, the level of visual perception increased. The orange peel effect was not perceived well visually on the roughness of samples N1~4, but visual perception was quite high on the orange peel effect regarding the roughness of samples N5~N10. From Figure 4, the samples were numbered in the order of increase in orange peel effect (namely, roughness), and the sample with the highest orange peel effect was numbered 7. Therefore, the roughness of sample N7 and its visual perception were the highest.

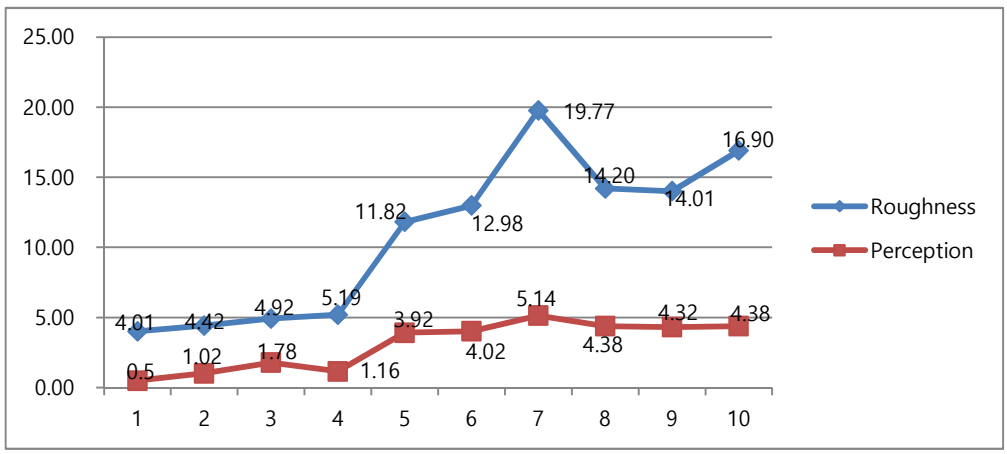

Figure 4. Visual perception level with surface roughness

Consequently, subjects of the experiment visually perceived the orange peel effect well on the roughness of 11.82μm and more, although they did not visually perceive well on the roughness of 5.19μm and less.

To find out the results above in more detail, this study conducted sample clustering, according to visual perception level on the

orange peel effect through a cluster analysis. According to the cluster analysis in Figure 5, the samples can be classified into two clusters. N1~N4 were classified into one cluster and N5~N10 were classified into another cluster. Such a result is the same as the significance analysis result with hugely different visual perception levels between N4 and N5.

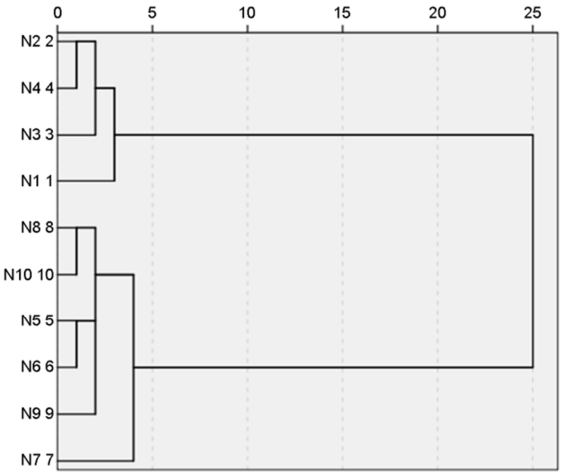

Figure 5. Dendrogram from cluster analysis

4.2 Emotional satisfaction with orange peel effect on surface

To find out what impacts of the orange peel effect caused in the sample's processing or coating process have on emotional satisfaction, this study carried out ANOVA on the basis of the subjective evaluation results. According to the analysis result as shown in Table 6, the orange peel level of the samples significantly affected the subjects' emotional satisfaction ($p = 0.00 < 0.05$).

Table 6. ANOVA for emotional satisfaction with orange peel effect

		Sum of square	df	Mean square	F.	Sig.
Satisfaction	Between group	509.459	9	56.607	30.708	.000
	Within group	897.736	487	1.843		
	Sum	1407.195	496			

As exhibited in Figure 6, as the samples' orange peel effect is remarkable, the emotional satisfaction on the surface texture becomes lower overall, and emotional satisfaction difference between sample N4 and N5, of which roughness difference is huge as equally as the visual perception, is conspicuous. Looking at Figure 6, the roughness of sample N7 was the biggest, because the same samples were used in visual perception evaluation, and the emotional satisfaction was low.

The results above are closely related with visual perception, according to roughness. That is, because the subjects' visual perception levels for samples N1~N4 were low, its emotional satisfactions were high. However, because visual perception levels for samples N5~N10 were high, its emotional satisfaction were low.

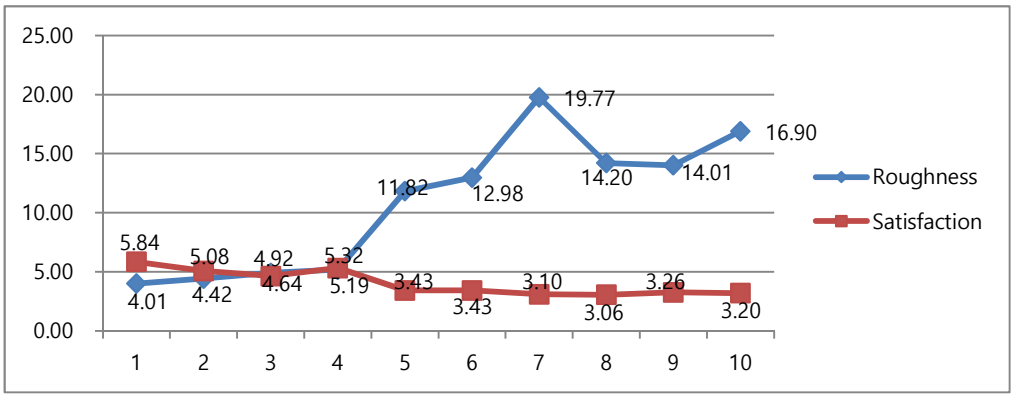

Figure 6. Emotional satisfaction with surface roughness

4.3 Correlation analysis among surface roughness, visual perception, and satisfaction

It was identified that visual perception level was higher and emotional satisfaction was lower, as the orange peel effect on the surface was more remarkable through the analysis of visual perception and emotional satisfaction. From the result, the significant correlation is supposed to exist among surface roughness indicating surface orange peel effect, visual perception and emotional satisfaction. To find out correlations, this study carried out a correlation analysis.

Table 7 reveals the results of a correlation analysis among the surface roughness, emotional satisfaction and visual perception, according to the orange peel effect. Roughness shows a negative correlation (r= -0.555) with emotional satisfaction, and a positive correlation (r= 0.807) with visual perception level. Such a result matches up with the results in Figure 4 showing visual perception and Figure 6 demonstrating satisfaction, according to samples' roughness. The correlation coefficient (r= -0.583) of visual perception and emotional satisfaction on the orange peel effect shows a negative correlation. From this, as the subjects visually perceive the orange peel effect, it is known that the visual perception affects the emotional satisfaction on surface texture.

Table 7. Correlation Analysis among roughness, satisfaction, and perception

Measure	Roughness	Satisfaction	Perception
Roughness	-	-0.555**	0.807**
Satisfaction	-0.555**	-	-0.583**
Perception	0.807**	-0.583**	-

**sig. at 0.01

4.4 Viewing patterns and evaluation criteria for the orange peel effect of surface in visual perception process

In this study, it was investigated what criteria the subjects used to visually judge the orange peel effect (Duplicated answers were allowed). The opinions on the question have been grouped with six categories as demonstrated in Table 8. Although, various opinions were drawn from subjects, their opinions were categorized into six categories in consideration of opinion similarities.

Looking at Table 8, the subjects considered curve density a lot in visually judging the orange peel effect level, and answered that the orange peel effect was stronger, as density was higher. And then, they used the particle's curve depth and height as important judgment criteria. They judged that orange peel effect was more severe, as the particle's curve depth and height were higher.

To find out eyes' movement of the subjects on the visual exploration process of the orange peel effect, this study measured the pupils' movement using an eye tracker during the exploration. From Figure 7 showing the movement of eyes, the subjects browsed a sample overall, and intensively observed the part where orange peel effect was demonstrated.

Table 8. Evaluation criteria for the orange peel effect of surface

Evaluation criteria of visual perception	Frequency
Density of OP phenomenon	17
Depth and height of curve	12
Surface reflection for light	9
Smoothness of surface	4
Intensity of pattern	3
Others	8

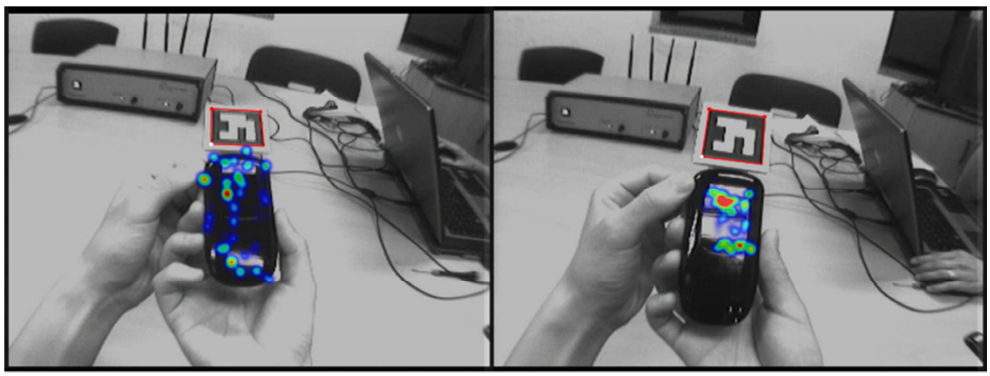

Figure 7. Heat map for scanning the orange peel effect of surface

5. Conclusion

Even surface treatment is essential for the high quality products demanded by buyers. The texture of visually uneven surface is an important factor degrading product quality. The orange peel effect is a representative phenomenon demonstrating the unevenness of surface, and is one of the causes negatively affecting emotional satisfaction with a product.

In this study, human visual perception and emotional satisfaction with orange peel effect were analyzed. As the orange peel effect is remarkable, the perception level on visual unevenness goes up, and it results in lower emotional satisfaction. Even though the orange peel effect exists, if visual perception level is not high, it does not have an impact on satisfaction much. From the study results, it is necessary to minimize the orange peel effect to the extent that users cannot visually perceive the orange peel

effect in order to enhance users' emotional satisfaction with surface texture.

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