Virtual Prototyping with Real-Time Rendering for Kansei Engineering of Leather Grain Patterns on Car Dashboard Panels

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Abstract: Along with recent developments of industrial finishing of plastics, simulating surfaces is much desired in industries. This research attempts to build a virtual prototyping system for surface finishing. Simulating surfaces will accelerate to Kansei-oriented product development without large cost of making real prototypes. Since the developed system renders *bumpy* and glossy surfaces in real-time, evaluator can accurately examine surfaces. As an application of the system, leather grain patterns of car dashboard were simulated. At first, surface details of car dashboards were measured with a laser 3D range finder device. Then, Kansei evaluation was done with 30 virtual prototypes those have variations on cars, intensity of roughness and with or without gloss. The evaluation result was analyzed with PCA and 3-factor ANOVA. Expression capacity of the system was validated with ANOVA results, those show significant effects of virtual prototype parameters on Kansei evaluation.

Keywords: *CG, Virtual prototyping, Real-time rendering, Material appearance, Surface finishing*

1. INTRODUCTION

In industries, recent developments of molding and industrial finishing techniques make it possible to control the appearance on surface of plastics. Variety of plastic products came to have rich appearances. From electronic products, car parts to building materials, plastic products with rich surface textures are widely used. Moreover, Kansei engineering techniques can be applied to R&D process of plastics and composite products.

However, because prototyping is expensive and only a few prototypes can be used for evaluating a product, finishing is often not viewed as a priority. Kansei evaluation with virtual products, which can show surface appearances without fabricating real prototypes, therefore poses an attractive prospect.

Virtual prototyping involves making three-dimensional computer model using measured or design data and requires cutting-edge techniques involving 3D Computer Graphics. Since common computer-aided design (CAD) systems do not generally have advanced display functionality, a customized system for rendering the model must be built. As noted above, surface finishing should be faithfully displayed.

In Kansei engineering, VR and real-time rendering Techniques have been explored and applied from more than 15 years ago. Jindo, Hirasago & Nagamachi [1] was an early attempt to make Kansei Engineering system has 3D Graphics. Nomura, Iwamura, Enomonoto & Nagama-

chi [2] was a large scale commercial VR system of built-in kitchens, which was used cutting edge VR computer systems at that time. At first, visitors at virtual showroom had filled Kansei preference and lifestyle questionnaire. Then the system shows the most appropriate concrete kitchen room image in VR, based on Kansei design databases. Possible kitchen layouts are over 30,000. A visitor can choose one's preferred kitchen parts and modify them in the VR. Finally, a decided plan and required parts were made into a plan sheet. Since possible designs and parts combinations are almost countless, pre-rendered scenes could not be used. At that time, huge and expensive VR machines were dedicated the system. VR or VR-like realization have been popular industries in a decade. Along with the prevailing of industrial real-time 3D or VR system, more detailed expressions become demanded for making virtual prototype. Expressing details of the object surface requires a detailed model, which is computationally expensive, and several minutes to hours a powerful machine may be required for conventional rendering of complex objects and scenes.

The nature of human visual cognition is such that people often perceive surface roughness and glossy finishing by viewing an object from different angles, moving it or themselves, with cognitive assumptions of lighting [3]. A still image or a movie from a fixed viewpoint is not sufficient for displaying and evaluating surfaces. Therefore, manipulation of viewpoint at the viewer's will is required for a surface perception. One approach for this requirement is preparing rendered images that a viewpoint is

manipulated, but this process takes much memory. Practical approach is real-time rendering of a surface on the virtual prototyping system, the system requires real-time responses for manipulating objects.

To summarize, real-time rendering is indispensable for dealing with both inquiring of surface finishing and Kansei engineering VR system with lower number polygon data.

To accomplish requirements, we created a virtual prototyping system that implements real-time rendering. It can express different material appearances without complex object data. Real-time rendering for material appearances is achieved with a bump-mapping technique by programming the graphic processing unit (GPU) as a vector processor.

The performance of the system was evaluated using with Kansei evaluation experiments of leather grain patterns for a car dashboard. We investigated the effects of varying the surface bumpiness and gloss.

2. COMPUTATION MODEL OF MATERIAL APPEARANCE

2.1 Cognition of material appearances

In this paper, “material appearance” refers to the physical attributes of the surface affecting light reflection. Materials such as metals, woods, plastics and marble appear different because they have reflective properties.

The appearance of a material largely depends on surface its bumpiness. According to cognitive science studies on “visual search” [3], perception of bump difference is more difficult than differences in line drawings or colors. Therefore, the perception of surface bumpiness involve the different perception processes. The first process involves determination the position of the light source, as inferred from object shading. The second process is to compare the shades due to differing positions of the light sources. This process requires time, as a range of viewing angles or some rotation of the object is required for perceiving the surface texture. Therefore, human changes viewpoints or object angles for validation of the perception. Then, the lights and the shadows vary on the surface. Human recognizes variation of the light and shadows as material appearance of the surface.

A virtual prototyping system must have some ability to maneuver objects at the viewer’s will and real-time rendering is necessary to achieve this.

2.2 Computation of material appearances

Ray-tracing and radiosity are the principal methods used in computer graphic. These methods have been developed for computing global illumination. On the other hand, expression of material appearance is generally

achieved using computation of local light illumination-based shading. The computation is performed on the inside points of the surface polygon. Light reflection attributes are described by geometric computations.

2.2.1 Phong reflection model

Material appearances are expressed as pixel color by computing the reflection light from the object and a mathematical reflection model is required.

The Phong reflection model [4] is a generalized local reflection model and that can express both reflection and lay diffusion from a material surface. Since the Phong model does not require integration which is needed by other models, its calculation amount is relatively smaller. As shown in Figure 1, it considers three kinds of reflection, specular reflection, diffuse reflection and ambient light. Specular reflection is the straight reflection of the ray from light source, thus it expresses a glossy appearance on the surface. Diffuse reflection causes spreading of the reflected rays (i.e., the reflected rays have some distribution of directions) and gives rise to appearances such as that of papers and fabrics. Equation 1 is the Phong reflection model, and we use this equation as basic determinant of pixel color.

$$I = K_a I_a + I_i (K_d (\mathbf{N} \cdot \mathbf{L}) + K_s (\mathbf{R} \cdot \mathbf{V})^n) \quad (1)$$

I = total illumination

K_a = ambient intensity, K_d = diffuse intensity

K_s = specular intensity

I_i = light source radiance, I_a = ambient radiance

$\mathbf{N}$ = surface normal, $\mathbf{L}$ = light source direction

$\mathbf{V}$ = view direction, n = specular power

Surfaces appearance differ depending on the surface finishing, even they are made of the same materials. For this reason, physical-based reflection model is required for these surfaces. But using some reflection models is so complicated for Kansei evaluation. There are several

Figure 1: Phong reflection model

methods for expressing surface properties related to lay. Although BRDF (Bidirectional Reflectance Distribution Function) is the most accurate method which directly expressing distribution of reflected rays, but it requires precise measurement of material reflection with optical devices. Torrance, Sparrow [6] and Cook [7] are other surface reflection models. They have many parameters and relations between parameters and rendered appearances are not straight forward. Then, we decided to utilize Phong reflection model since smaller number of parameters, simplicity of the physical model and plausibility to represent different materials. In Phong model, material surface is multilayered and each layer has different reflection properties. Utilizing Phong model, surface that has complex reflection properties can be modeled.

2.2.2 Expression of surface bumpiness with Bump mapping}

In most cases of rendering, the polygons are larger than one graphic pixel.

As shown in Figure 2, in the Phong model, the normal vector of each pixel is obtained from a linear interpolation of the vertex normals of a polygon. Specular and diffuse reflection from each pixel is modified with the above interpolation.

One strategy for expressing more surface detail is using a large number of small polygons, although this requires more memory, computation and time for model building.

We used a Bump Mapping technique [8-12] to obtain high-resolution normals without using many polygons or dividing polygons. Figure 3 shows the basic idea of bump mapping. There are surface $\mathbf{P}$, function F and perturbed surface $\mathbf{P}'$ according to F . Bump mapping obtains the normals of a new $\mathbf{P}'$ and reflects them to $\mathbf{P}$. A height map on the surface $\mathbf{P}$ is shown and a coordinate of a point on the map is defined (u, v) .

Relations among $\mathbf{P}$, F and $\mathbf{P}'$ are defined in Equation 2. $\mathbf{N}$ is a normal vector on $\mathbf{P}$ and the result of F is a scalar.

$$\mathbf{P}'(u, v) = \mathbf{P}(u, v) + F(u, v) \frac{\mathbf{N}(u, v)}{\|\mathbf{N}(u, v)\|} \quad (2)$$

Figure 2: Linear interpolation gives polygon pixel normals

Figure 3: Bump mapping treats smooth surface as rough surface

$\mathbf{N}'$, a normal of $\mathbf{P}'$ is defined with Equation 3.

$$\mathbf{N}'(u, v) = \frac{\partial \mathbf{P}'(u, v)}{\partial u} + \frac{\partial \mathbf{P}'(u, v)}{\partial v} \quad (3)$$

$\mathbf{P}'$ is required for obtain $\mathbf{N}'$. Equations 4 and 5 define partial differentials of $\mathbf{P}'$ with respect to u and v . The value of the last terms in the Equations 4 and 5 are very small and can be neglected.

$$\frac{\partial \mathbf{P}'}{\partial u} = \frac{\partial \mathbf{P}}{\partial u} + \frac{\partial F}{\partial u} \left(\frac{\mathbf{N}}{\|\mathbf{N}\|} \right) + F \left(\frac{\partial}{\partial u} \left(\frac{\mathbf{N}}{\|\mathbf{N}\|} \right) \right) \quad (4)$$

$$\frac{\partial \mathbf{P}'}{\partial v} = \frac{\partial \mathbf{P}}{\partial v} + \frac{\partial F}{\partial v} \left(\frac{\mathbf{N}}{\|\mathbf{N}\|} \right) + F \left(\frac{\partial}{\partial v} \left(\frac{\mathbf{N}}{\|\mathbf{N}\|} \right) \right) \quad (5)$$

The outer product of Equations 4 and 5 is $\mathbf{N}'$.

$$\mathbf{N}' = \frac{\frac{\partial F}{\partial u} (\mathbf{N} \times \frac{\partial \mathbf{P}}{\partial v}) - \frac{\partial F}{\partial v} (\mathbf{N} \times \frac{\partial \mathbf{P}}{\partial u})}{\|\mathbf{N}\|} \quad (6)$$

Since the partial differentials in Equation 6 could not be computed, then Blinn gives two different representations of Equation 6 for solving. One of the representations considers the perturbation of $\mathbf{N}$ as a rotation of vector $\mathbf{N}$. $\mathbf{D}$ is defined as the perturbation of $\mathbf{N}'$ from $\mathbf{N}$. $\mathbf{N} \times \mathbf{N}'$ is expressed as Equation 7.

$$\mathbf{N} \times \mathbf{N}' = \mathbf{N} \times (\mathbf{D} + \mathbf{N}) = \mathbf{N} \times \mathbf{D} \quad (7)$$

By expanding Equation 7, we obtain Equation 8.

$$\mathbf{N} \times \mathbf{N}' = \frac{\frac{\partial F}{\partial u} (\mathbf{N} \times (\mathbf{N} \times \frac{\partial \mathbf{P}}{\partial v})) - \frac{\partial F}{\partial v} (\mathbf{N} \times (\mathbf{N} \times \frac{\partial \mathbf{P}}{\partial u}))}{\|\mathbf{N}\|} \quad (8)$$

Using an identity of vectors, Equation 8 can be simplified as Equation 9.

$$\mathbf{N} \times \mathbf{N}' = \|\mathbf{N}\| \left(\frac{\partial F}{\partial v} \frac{\partial \mathbf{P}}{\partial u} - \frac{\partial F}{\partial u} \frac{\partial \mathbf{P}}{\partial v} \right) \quad (9)$$

The vector $\mathbf{A}$ is perpendicular to the gradient vector of

F . Each vector is shown in Figure 4. The Rotation amount is determined by the relationship $\mathbf{N} \times \mathbf{D} = \|\mathbf{N}\| \mathbf{A}$. Since $\|\mathbf{N} \times \mathbf{D}\| = \|\mathbf{N}\| \|\mathbf{D}\|$, then

$$\|\mathbf{D}\| = \|\mathbf{A}\|$$

$\mathbf{N}$, $\mathbf{D}$ and $\mathbf{N}'$ form a triangle, and a rotation amount θ by perturbation is defined as Equation 10. Figure 5 shows the relations among θ , $\mathbf{N}$ and $\mathbf{N}'$.

$$\tan(\theta) = \frac{\|\mathbf{N}\|}{\|\mathbf{D}\|} = \frac{\|\mathbf{N}\|}{\|\mathbf{A}\|} \quad (10)$$

Implementation of bump mapping requires the generation of a normal map from bump function F which can be expressed as a height map. Figure 6 shows height map and the generated normal map. With the implementation of bump mapping, our system can express the complicated texture of a material surface. Figure 7 shows the bump-mapping results, both with and without bump mapping.

2.3 Building the virtual prototype system

To model a detailed material surface using bump mapping, a considerable amount of computation time is required. This is too long for real-time rendering using only a CPU. We thus used Graphic Processor Unit (GPU) as vector processor for real-time rendering.

We created the framework of the virtual prototyping

Figure 4: Vector $\mathbf{A}$ and Normal $\mathbf{N}$ Figure 5: Vectors and θ

Figure 6: Height map (left) and Normal map (right)

system with GLSL [13], which is the OpenGL advanced library. Although OpenGL is a widely used graphics interface, it has only a limited surface appearance. GLSL is one of the custom shaders, which defines surface appearance computation and uses the GPU.

GLSL consists a vertex shader process and a pixel shader process. The vertex shader computes polygon vertices as a vector array, and it outputs transformed vertices to the rasterizer. The pixel shader computes the color pixels of the image from rasterized pixels. Finally, the CG image is shown on the display.

Figure 8 shows the shader processes which construct graphics from polygon vertices, matrices, light properties and textures.

Our system displays over 30 frames per second with real-time rendering, it takes about less than 0.01 second per image.

Figure 7: Bump mapping result; left:without bump mapping right:with bump mapping

Figure 8: The vertex shader process and the pixel shader process

3. KANSEI EVALUATION OF CAR DASHBOARD PANELS

In this section, we examine the virtual prototyping system's ability to express details of surface finishing. Leather grain patterns were measured from real car dashboards and Kansei evaluation experiments carried out using virtual prototypes with varied bumpiness.

3.1 Making virtual prototypes from measurement of car panel

To obtain the surface patterns, we measured the leather grain patterns from the dashboard panel of 5 cars (A1, A2, W1, C1 and T1). A 3-D measurement of the dashboard surface was achieved using a laser range finder (Minolta VIVID 900). Figure 9 shows the measurement setup.

The first step of model building is to make a height map. 3D data were created using the depth data measured with the range finder, using Polygon Editing Tool ver. 2.21 (Konica Minolta). Then, a square region which has smaller measurement errors was selected from the 3D data and the depth was expressed as darkness in grayscale map. Finally, a normal map was generated from the grayscale map.

We systematically varied the intensity of the roughness (3 different settings) and used 2 different light reflectances, producing 30 (6 variations of 5 cars) prototypes were used the experiment. Figure 10 shows the virtual prototypes.

Figure 9: Setup of car dashboard panel measurement

3.2 Evaluation of dashboard panel virtual prototypes

Kansei evaluation experiment was carried out using a questionnaire that have 48 word pairs of semantic differential scale. The words are arranged from [15], and they include Kansei words those had commonly used for various product development cases. Twenty-one college students participated in the evaluation (Female 9 and Male 13). Subjects manipulated the view angle and light direction as they saw enough during the evaluation. We asked students who are studying Kansei engineering as subjects, since the differences of the surfaces are delicate, and evaluations require concentrations.

4. ANALYSIS RESULTS AND CONSIDERATIONS

4.1 Kansei Structure

We analyzed the data from the Kansei evaluation using Principal Component Analysis (PCA). The 1st PC's contribution ratio is 77% and that for second PC is 7%, third PC scores 2%. Figure 11 shows the plot of PC loadings. With PC 1, *modern*, *over-decorated*, *rough touch*, *coarse* and *warm* are located on the right side and *chill*, *sharp*, *plain*, *natural* and *monotonous* are located on the left side. PC 1 is named as the “modern vs natural” axis. For PC 2, *gorgeous* and *unique* are located on the bottom side and *somber* is on the upper side. PC 2 is called “decorativeness”. In Figure 12, along PC 3, *natural*, *somber*,

Figure 10: Virtual prototypes;
T1 prototypes;
top-left: not grossed, 0.5 bumpiness
middle-left: not grossed, 1.0 bumpiness
bottom-left: not grossed, 2.0 bumpiness
top-right: grossed, 0.5 bumpiness
middle-right: grossed, 1.0 bumpiness
bottom-right: grossed, 2.0 bumpiness

tender and *adult* are located on the bottom side and *refined*, *gorgeous* and *premium* are located on the upper side. PC 3 is named as “premium” and “refined”. The contribution ratio of 1st PC is very large and the after ratios are small, that means The 1st PC is the decisive factor. *sculptural*, *bumpy* and *real* or *plain*, *airy* and *light* are significant components on the evaluations of virtual prototypes. Those words have large variance among the samples. In addition, we consider that the first principal component well represents the characteristic texture of leathers. Therefore, The result supports that our participants recognized three-dimensional appearance of virtual prototypes as we intended.

There are several salient counter point structures. *Masculine*, *hard* and *dark* are at the upper-right and *feminine*, *soft* and *tender* are at bottom-left. This structure defines the gender and solidness of a surface.

Another counter point is formed by *unique*, *gaudy* and *individual* at the bottom-right, and *somber* at the upper-left. This structure indicates the uniqueness of a surface.

4.2 Relations among bumpiness, gloss and Kansei

From results of PCA, we obtained principal component score of virtual prototypes. Figure 12 shows the PC scores of panel prototypes and axes. Each dot represents a prototype. The first term of the label is the the car name, the second term is the magnification of surface roughness, and the terms in parentheses indicate the light reflectance. (“n” means “not glossed” and “g” means “glossed”).

“ $\times 0.5$ / $\times 1.0$ / $\times 2.0$ bumpiness” means magnification of measured surface bumps, the range of the bumpiness is decided by range of real products. We consider the differences among the car dashboard panels, the combination effects of magnifying the surface bumpiness, and light reflectances. The magnification of bumpiness influenced the structure significantly. Prototypes of $\times 0.5$ bumpiness are located at the left part of Figure 12, and correspond to *textit{plain}*, *airy*, *light* and *tender*. The $\times 1.0$ bumpiness prototypes are at the middle-center and correspond to *textit{adult}*, *premium* and *refined*. The $\times 2.0$ bumpiness prototypes are at the right and correspond to *individual*, *bumpy*, the *novel*, *real*, *rich-textured*, *sculptural* and *over-decorated*.

Glossed / not glossed has moderate effects. Although no common movement is observed at $\times 0.5$ and $\times 1.0$ bumpiness, movements occur at $\times 2.0$ bumpiness. Most glossed (g) prototypes move to the right, from a position of indicating without gloss (n). This result means that at $\times 2.0$ bumpiness, the effect of gloss is apparent to the subjects. Next we consider each car pattern. A2 moves from the left to the middle according to the bumpiness magnification. A1 is more *somber*. A1 $\times 0.5$ (g) has a specific *somber* Kansei.

Figure 11: Principal component loadings (1st - 2nd)

Figure 12: Principal component loadings(1st - 3rd)

Figure 13: Principal component scores and significant component axes

C1 at $\times 0.5(g)$ is more *tender*. It also moves toward the right, C1 at 2.0(g,n) are *over-decorated* and *rich-textured*. Most of the T1 variations are located at the lower part of the graph and correspond to *gorgeous*, *elegant* and *individual*. W1 prototypes are in middle-center, W1 at $\times 0.5(n)$ is close to *natural* and $\times 0.5(g)$ is *childish*. $\times 1.0(n)$ corresponds to *refined* and *premium*.

A1 prototypes locates Somber side of “Somber - Gaudy” structure. They are *somber*, *simple* and *plain*. In the Gaudy side, T1 prototypes are *gorgeous*, *individual* and *sculptural*.

The characteristics of each car dashboard seemed to be well expressed in virtual prototypes.

4.3 Effectiveness validation of virtual prototyping on Kansei evaluation

To validate the effectiveness of virtual prototyping parameters on Kansei evaluations, analysis of variance was performed. There are 3 parameters of virtual prototypes (surface patterns from 5 cars, 3 intensities of roughness and 2 surface glossed/not glossed), and we used a 3-factor ANOVA model with repeated measurements [14]. ANOVA was examined on representative Kansei words on Kansei structure; *tender / hard*, *feminine / masculine* and *gaudy / somber*.

For *tender*, the surface pattern [$F(4,84) = 6.0245$, $p < .001$] and the intensity of roughness [smaller is more soft, $F(2,42) = 17.659$, $p < .001$] have statistically significant main effect. Interaction between the surface pattern and the intensity of the roughness [$F(8,168) = 3.6608$, $p < .001$] is also significant.

Hard has main effect of the surface pattern [$F(4,84) =$

3.3609 , $p < .05$] and the intensity of roughness [larger is harder, $F(2,42) = 15.651$, $p < .001$]. Interactions between the surface pattern and the intensity of surface roughness [$F(8,168) = 3.2384$, $p < .01$], and the interaction between [$F(4,84) = 2.6923$, $p < .05$] are significant.

In Figure 14, samples of larger bumpiness magnification locates right hand side, smaller bumpiness locates left side. This shift is also shown in Figure 14. Larger bumpiness is less *tender*, more *harder*. Idiosyncrasy of the car is also shown. A2 has smaller effect of bumpiness magnification. These results show effects of both surface pattern difference and bumpiness magnification in evaluations.

There are significant main effects on *feminine*, on the surface pattern [$F(4,84) = 2.5826$, $p < .05$], the intensity of roughness [smaller is more feminine, $F(2, 42) = 21.62$, $p < .001$], and glossed / not glossed [not glossed is feminine, $F(1, 21) = 5.3018$, $p < .05$]. The surface pattern and intensity of roughness interact [$F(8,168) = 4.1981$, $p < .001$], the surface pattern and glossed / not glossed also interact [$F(4,84) = 7.8789$, $p < .001$].

For *masculine*, there are main effects on surface pattern [$F(4,84) = 2.5826$, $p < .05$], the intensity of surface roughness [larger is more masculine, $F(2,42) = 33.144$, $p < .001$] and the glossed/not glossed [glossed is more masculine, $F(1,21) = 13.653$, $p < .01$]. The surface pattern and intensity of roughness have an interaction [$F(8,168) = 2.7096$, $p < .01$], the surface pattern and glossed / not glossed have an interaction [$F(4,84) = 5.633$, $p < .001$].

Smaller intensity of roughness is more *feminine*, larger intensity is more *masculine* (Figure 15). Surface patterns of A2 and W1 have the interaction effect. In Figure 16,

Figure 14: Interaction plot between the surface pattern and the intensity of roughness (bump factor);
top: mean values of *tender*
bottom: mean values of *hard*

Figure 15: Interaction plot between the surface pattern and the intensity of roughness (bump factor);
top: mean values of *feminine*
bottom: mean values of *masculine*

although glossed surface shows more *masculine* and less *feminine*, A1 and W1 also have idiosyncratic interactions.

Gaudy has main effects on the surface pattern [$F(4,84)=12.231$, $p<.001$] and intensity of roughness [larger is more gaudy, [$F(2,42)=16.546$, $p<.001$]]. Interaction of the surface pattern and glossed / not glossed is found [$F(4,84)=2.6089$, $p<.05$].

Somber has a significant main effect on surface pattern [$F(4,84)=12.308$, $p<.001$] and intensity of surface roughness [$F(2,42)=4.8618$, $p<.01$], the surface pattern and intensity of surface roughness have an interaction [$F(8,168)=2.0116$, $p<.05$].

In Figure 17, larger intensity of roughness is more Gaudy and less Somber. T1 is gaudy and $\times 2.0$ bump of C1 is most gaudy. A2 has a weak interaction effect.

Analysis results of this section demonstrate that polarized structure on both Kansei and surface parameters. Tender and hard, opposing relation of the Kansei, have also polarized structure on intensity of roughness. Larger roughness is harder, lesser is tender. Feminine and masculine have inverse relation on both roughness and gloss. Feminine is smaller roughness and not glossed. Masculine is larger roughness and glossed. Gaudy and somber, another opposing relation of the Kansei has difference on roughness. Larger roughness is gaudy, smaller is somber. From these results, effectiveness of surface parameters is shown on Kansei evaluation.

4.4 Considerations and implications on validation

Every representative Kansei word has significant effects on “intensities of roughness” and/or “surface patterns”. For *feminine* and *masculine*, also glossed has a significant

effect. Thus, differences in the parameters of virtual prototypes seem well effected to Kansei evaluations. Some Kansei words have interaction effects among the parameters. In addition to Kansei words discussed so far, some other words have interactions among all three factors; *airy* [$F(8,168)=2.7361$, $p<.01$], *feminine* [$F(6,168)=3.1467$, $p<.01$], *refreshing* [$F(8,168)=2.2002$, $p<.05$]. These words have the main effect of the intensity of roughness (*airy*: [$F(2,42)=55.522$, $p<.001$]; *feminine*: [$F(2,42)=21.62$, $p<.001$]; *refreshing*: [$F(2,42)=37.214$, $p<.001$]).

These results imply that surface roughness variations based on bump factors have largest effects. Idiosyncrasies in the surface patterns of various cars are also suggested from the interaction effects. We consider again on bump-mapping parameter and its relations between intensity of surface roughness and idiosyncrasy of cars. Figure 18 shows the distributions 2-dimensional θ , rotation of the normal which defined by the Equation 10. Standard deviations of θ of C1, at various intensity of surface roughness are 1.40 degree (horizontal), 2.05 degree (vertical) at $\times 0.5$ intensity. On $\times 1.0$ intensity, 2.73 (H) and 4.07 (V) and on $\times 2.0$ intensity, 5.22 (H) and 8.08 (V). At patterns of A2, 0.91 (H) and 1.34 (V) at $\times 0.5$ intensity, 1.87 (H) and 2.57 (V) at $\times 1.0$ intensity and 3.83 (H) and 5.08 (V) at $\times 2.0$ intensity. C1 has about 1.5 times larger standard deviation than A2. Differences of cars are also shown in statistical measure. It implies that the variation of the surface pattern, the intensity of surface roughness and glossed / not glossed affect the Kansei evaluation value and fine-tuning of surface finishing should be carefully considered to produce an attractive product.

Figure 16: Interaction plot between the surface pattern and the glossed/not glossed;
top: mean values of *feminine*
bottom: mean values of *masculine*

Figure 17: Interaction plot between the surface pattern and intensity of roughness (bump factor)
top: mean values of *gaudy*
bottom: mean values of *somber*

Figure 18: The distributions 2-dimensional θ , rotation of the normal

5. CONCLUSION

Cognitive science studies show that our visual cognition system has a strong assumption of lay and manipulating of the viewpoint or object is required for recognition of surface details. Thus, real-time rendering is an indispensable function for evaluation of the surface finishing, for moving light source or object at user's will.

Phong reflection model and bump mapping technique were used as the mathematical models of surface. These models are relatively simpler and more plausible for wider material surfaces than other specific models.

We have set three intensities of bumpiness and with or without gloss for virtual product samples. Intensities were $\times 0.5$, $\times 1.0$ and $\times 2.0$. The range of the intensities is decided by range of real products. Leather grain surface patterns were taken from 5 real cars.

Kansei evaluation was done with 22 subjects. Conditions of the Kansei evaluation experiment were intensities of bumpiness, leather grain patterns and gloss / no gloss. From the results of principal component analysis and ANOVA, effects of the conditions on Kansei evaluations were salient and accord with Kansei structures.

In this study, simulated surface was limited to opaque materials. Transparent or half-transparent materials such like marble, frosted glass and human skin require other mathematical models. At further perspective of our study, the system can be applied to not only the leathers but also

papers and metals.

In conclusion, the results of this analysis provide the possibilities of virtual prototyping with real-time rendering. Utilizing this technology, Kansei evaluation will be more applicable to research and development periods of many kinds of products. Then, Kansei engineering methodologies will spread larger number of industries.

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