Device Independent Graininess Reproduction: Preliminary study

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In this paper, we propose a psychophysically-based model of graininess perception for device independent graininess reproduction system. This model is developed by conducting an experiment to explore the relationship among 1) subjective evaluation values for various graininess objects, 2) physical parameters used to generate the graininess objects and 3) values of maximum luminance on the display for reproduction. In the experiment to obtain the subjective evaluation values, the magnitude estimation method was used to quantify the graininess perception. The graininess model obtained by multiple regression analysis for the above values can be used to calculate curved surfaces where the graininess objects are observed as the equal appearance. This surface can be used for device independent graininess reproduction process to match the graininess under the displays with various maximum luminance. In this process, even if the values of maximum luminance on the display is changed in the model, the value of graininess under the changed luminance is hold by changing the physical parameters of graininess generation in the model. In the practical experiment, we found that the proposed model and process for device independent graininess reproduction were effective for our adopted displays with various maximum luminance.

1. Introduction

Recently, an electronic commerce such as online shopping becomes more active with powerful progress of high-speed network and computer science. Especially, the development of computer graphics (CG) technique and rendering engine have a great contribution for the advancement of electronic commerce. An excellent representation of commercial product excites consumer's interest, and an accurate representation with high quality makes possible the commerce transaction in the virtual world.

An accurate reproduction for material appearance is the most important factor for commercial value of product as the quality control of electronic commerce. Color matching technique is one of useful technique to fit the diffuse color and texture of the commercial product. This technique performs numerical calculation for color calibration between input device and display. Since the difference of appearance color becomes the cause of trouble, the maker of display device defines the range of representable color as the quality criteria, and performs the color calibration before the shipment of products.

On the other hands, the appearance of surface graininess is also important factor of product in the electronic commerce. The fine-grained surface with coating and polishing make a better impression as the premium products. Moreover, this characteristic of surface graininess involves the sense of touch and hold. It is significant sensibility for us to design the shape and function of product. Therefore, we become sensitive and pay attention to the appearance of surface graininess, even if the commercial product represents in the electronic commerce. The mischief is that this appearance has no responsibility for the representation on various kind of display device. Appearance matching method with similar manner to the color matching should be developed for the further electronic commerce growth. However, many parameters and complicate handling anticipate difficulties in the calibration of display device, because various kinds of display such as LCD, Organic LCD, and Inorganic EL are existed.

Therefore, in this paper, we propose a device independent reproduction method to match the appearance of surface graininess by the control of CG image as shown in Fig. 1. We derive the uniform perceptual space about surface graininess by experiment of magnitude subjective evaluation. Characteristics of devices witch change the appearance of surface graininess include resolution, maximum luminance, color reproduction range, and so on. By controlling the height and distribution of bump profile in CG image according to the maximum luminance as preliminary study, the proposed method can make a perception of surface graininess equal in each display device.

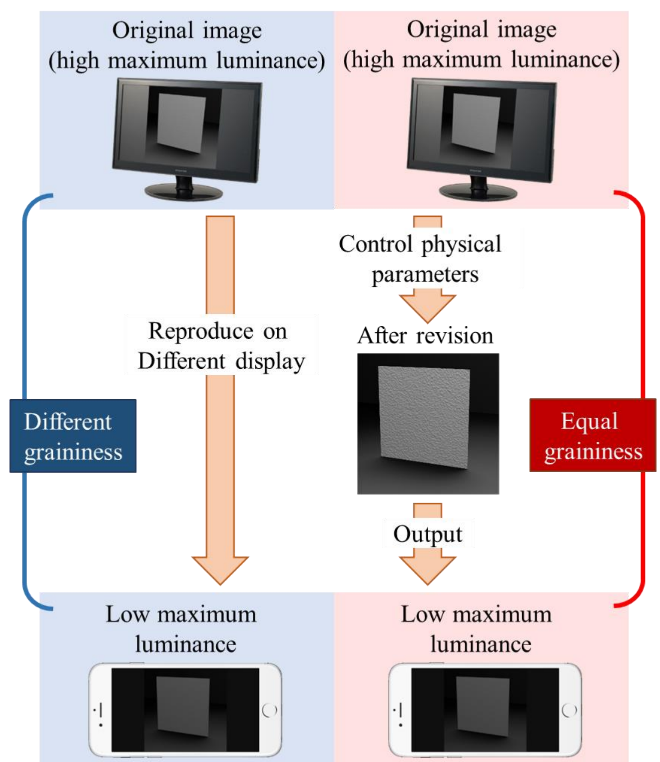


Figure 1 Outline of graininess matching

2. Related Works

A few number of researches have been performed about the appearance for graininess material with CG objects. Alternatively, some researchers studied about gloss which involves the graininess appearance as a perception of light scattering. Pellacini et al.[1] developed a new model based on experiments to quantify the perception of gloss on the object's surface. They conducted two experiments which explore the relationships between the physical parameters and the perceptual dimensions of gloss appearance. In the first experiment, they used a pair comparison method to reveal the dimension of gloss perception for simulated painted surfaces. From this experiment, they visualized the data by using multidimensional scaling techniques[2] and found the perceptual dimensions expressing two important features of the gloss appearance. These features are denoted by Eq. 1.

$$d = 1 - \alpha$$
$$c = \sqrt[3]{\rho_s + \rho_s / 2} - \sqrt[3]{\rho_s / 2} \ , \qquad (1)$$

where d and c are perceptual dimensions, and ρ_d is the object's diffuse reflectance, ρ_s is the specular reflectance, and α is the spread of the specular lobe, which are introduced by Ward's anisotropic BRDF model[3][4]. These dimensions of d and c are qualitatively similar to the contrast gloss and distinctness-of-image (DOI) gloss observed by Hunter[5]. In the second experiments, Pellacini determined the relationship between the perceptual dimensions of gloss appearance and the physical parameters used to describe the reflectance properties of glossy surfaces. They evaluated two kinds of objects described with c and d which are related to the physical dimensions such as ρ_d, ρ_s, and α. The magnitude estimation method is used to estimate the relationship between the physical quantity of stimulus and the human perception. From this experiment, we can compare the objects described with the physical parameters and the perceptual dimensions. This property of the model may make it more easier to create objects that have the same perception about gloss appearance.

As the other research about quantification for gloss perception, Ikeda et al.[6] conducted an experimental approach to reproduce an equal gloss object with CG even if the gloss object was presented on the displays which with different maximum luminance. In this experiment, they prepared images which varied the parameters of an intensity (A_1) and a spread of the specular reflectance (A_2) in Phong's model[7]. In addition, the other parameter is prepared as the maximum luminance V_{max} of a display. They used a magnitude estimation method to evaluate the gloss perception of these images. As the results of the multiple regression analyze of this data, they obtained a model denoted by Eq. 2

$$G = 54.7\sqrt{A_1} + 4.1 \times 10^2 \sqrt{A_2} + 5.4\sqrt{V_{\max}} - 76.3 \ , \qquad (2)$$

where the coefficient of determination (R^2) was 0.803 in this model. Therefore, this model had the good proportion of the variance in the dependent variable. This model indicates that the perceptual gloss G is possible to express with the physical gloss parameters A_1, A_2 and V_{max}. Therefore, an equal perception of the gloss depending on the maximum luminance of the displays is reproduced by adjusting A_1 and A_2.

3. Development of Perceptually Uniform Graininess Space

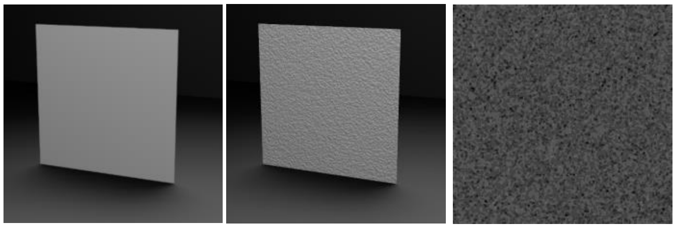
3.1. Generation of Experimental Images

Our experiment was intended to decide the perceptual tends and the elements of the graininess. Therefore, we reproduced the various patterns graininess object by using CG renderer. Here, we adopt the condition that the material object was made by mat as the first challenge. In order to produce the graininess, we used a bump mapping technique. This technique can render ruggedness on the flat object by changing the pixel value according to normal map. In this process, the direction of reflected light is changed in a pseudo manner according to a change of the texture's pixel value. Although the surface of the actual object is flat, it is possible to make it appear as if ruggedness exists by changing the appearance of object with shading and the shadow. Figure 2 indicates the rendering result by the bump mapping. Here, at the first impression about rendering result, some subjects point out the difference of graininess values depending on the region in this image. This difference is assumed by the generation algorithm of binary noise. Therefore, we added a Gaussian noise in order to obtain a uniform perception for graininess according to a normal distribution.

We anticipated that a depth for ruggedness and a size of the grain had a large effect to the graininess appearance in the rendered image. In our reproduction, the change of depth for ruggedness is generated by changing the pixel value of the normal map with the Gaussian noise. Also, the size of grain was varied by an operation of dilation in morphological processing. This dilation is one of the image processing used for the expansion of an element in the digital image. By the expansion of the element in the normal map for the bump mapping, the size of grain is larger in the object after processing. However, a rapid change of ruggedness as shown in Fig. 3(a) appears if the size of grain became large to a certain degree by the dilation. Therefore, we applied a Gaussian filter to the normal map after the dilation to smoothen the rapid change. Fig. 3(b) indicates the result after smoothing. In our experiment, the values of standard deviation for Gaussian filter was empirically decided by 0.3 times about the size of grain. Moreover, it is found that the graininess objects as shown in Fig. 3(b) are hard to feel the graininess because a hollowed condition appears. Therefore, by inverting the luminance value of the texture, we actualized the graininess objects shown in Fig. 3(c). Figure 3 is an enlarged view of the graininess object as the grain is easily perceived.

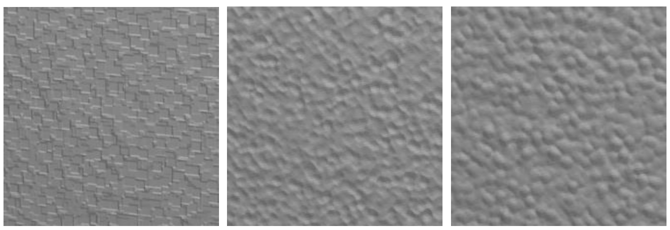
In addition to the parameters of the depth for ruggedness and the size of grain, we incorporated a parameter of the maximum luminance of a display. This parameter is dependent on the maximum pixel values of the displayed image. For the implementation of this parameter, it is necessary to check a corresponding relationship between the pixel values and the luminance of a display. We used an EIZO FlexScan S2001W monitor, and measured luminance with a chromameter CS-100A of KONICA MINOLTA. As the result of the measurement, we obtained a characteristic curve denoted by Eq. 3.

$$L = 0.001P^2 - 0.003P - 0.257 \ , \qquad (3)$$



(a) Before processing (b) After processing (c) Texture image

Figure 2 Processing of bump mapping



(a) Before processing (b) After smoothing (c) After inversing a luminance

Figure 3 Processing of producing graininess objects

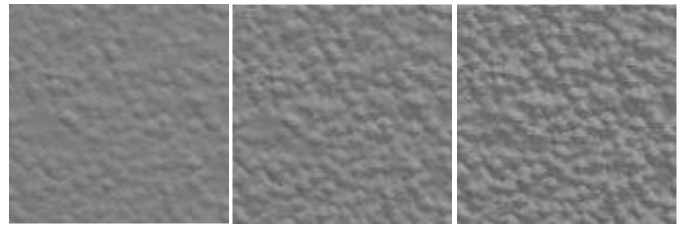
where the coefficient of determination (R^2) was 1.00. L is the luminance, and P is the pixel value of the display. According to Eq.3, it is assumed that changes of the maximum pixel values in the images are variations of the maximum luminance of the displays. Therefore, we can change the graininess image according to the maximum pixel value in the display.

3.2. Procedure

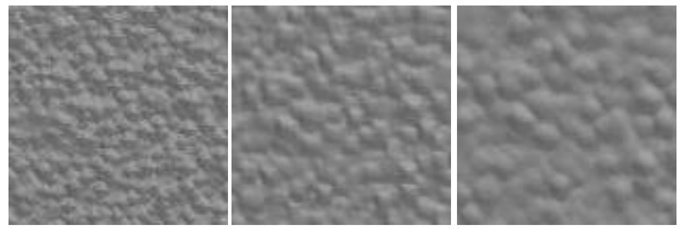
The purpose of our experiment is to create a perceptually uniform space for graininess in order to control graininess quantitatively. To make a perceptually uniform, we have designed an experiment based on magnitude estimation method. The magnitude estimation is one of psychophysical scaling techniques that can reveal functional relationships between the physical properties of a stimulus and its perceptual attributes.

Nine subjects participated in this experiment. The subjects consisted of college students of men and women having normal or corrected to normal vision. In the experiment, the subjects observed pairs of graininess images by generating CG renderer. These images were presented on a black background in a darkened room with the exception of unnecessary stimulus. The distance between the observer and monitor was about 40 inches which was 3 times of the height of display.

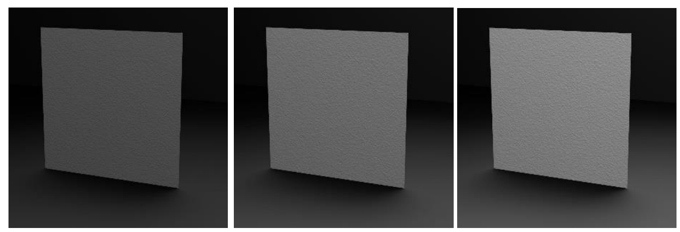
Each parameter of the experimental images was set to three levels as shown in Fig. 4. The depth for ruggedness A(Amplitude) values were (64, 128, 256), the size of grain S values were (2, 3, 4), and the maximum luminance L values were (11, 24, 35) respectively. In this experiment, 27 sequences of stimuli generated by setting the three variables were randomly displayed to the subjects. These images were rendered by changing these parameters: A, S and L. They are asked to assign the perceptual evaluation for graininess to each object on a scale from 0 to 100. The score of evaluation was from 0 as the smallest graininess to 100 as the largest graininess. Before this experiment, two typical objects which were 0 and 100 graininess were presented as a reference. The value of evaluation result in this experiment was



(a) A change of the depth for ruggedness



(b) A change of the size of grain



(c) A change of the maximum luminance

Figure 4 Examples of rendered experimental image

normalized to consider a personal difference of the judgments denoted by Eq. 4.

$$V_{\mathrm{normalized}} = \frac{V_i - MIN}{MAX - MIN}, \quad (4)$$

where $V_{\mathrm{normalized}}$ is the result of subjective evaluation after normalization, V_i is the evaluation score for each image, MAX is the maximum value and, MIN is the minimum value. By applying the formula, the score obtained by the experiment can be scaled from 1 to 0.

3.3. Results of Experiment

Equation 5 denote the result of a multiple regression analysis for the data obtained by the magnitude estimation.

$$G = 0.254 \times \sqrt[3]{A} - 0.480 \times \sqrt{S} + 0.006 \times L - 0.121, \quad (5)$$

where the coefficient of determination (R^2) was 0.763. A is the depth for ruggedness (Amplitude), S is the size of grain, and L is the maximum luminance value corresponding to the maximum pixel value in the image. G is the dependent variable related to the perceptual graininess. Using this model, we obtained the equal perception level on each graininess. Figure 5 indicates these results as a normalized graininess G = 0.2, 0.4, 0.6, 0.8, 1.0, respectively. These uniformed surfaces can be utilized to make us equal perception for graininess, if we control the parameters such as A, S and L. Therefore, when we select the value of A or S along the same surface according to the arbitrary maximum luminance of

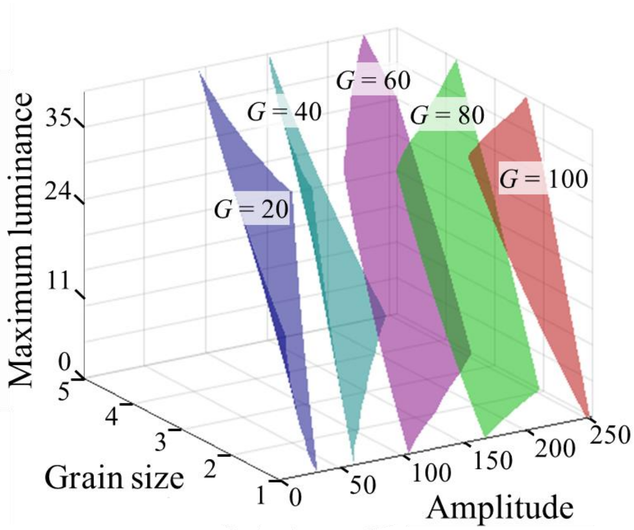


Figure 5 Uniformed surfaces of an equal graininess perception

display, the device independent reproduction for graininess can be acquired.

4. Discussion

In this chapter, we revise the appearance for graininess according to the proposed model. The value of graininess under the changed luminance is hold by changing the physical parameters of graininess generation in the model when the values of maximum luminance on the display is changed.

4.1. Matching Graininess Using the Model

As an example of revising perceptual appearance for graininess, we generated a graininess object on parameters: A = 128, S = 3, and L = 35. This objects is G = 0.54 on the uniform graininess surface. Here, this image defined as an original image in this evaluation. Next, we generated the comparison example with low maximum luminance on the display. This object was rendered by changing the parameter: A = 128, S = 3, and L = 11, which are lowered only in respect of the maximum luminance. It is assumed that changes of the maximum pixel values in the images are variations of the maximum luminance of the displays. The score of graininess (G) of this comparison example was 0.43 which was derived as the average of subjective evaluation. It is obvious that the score of evaluation is degraded according to the decrease of maximum luminance. This result indicate that subjects are hard to feel the appearance of graininess when the maximum luminance of display is decreased.

Next, we revise this image with the low maximum luminance to perceive equal appearance for graininess to the original image. In the first operation, we define the plain meaning that all values are equivalent according to the low maximum luminance: L = 11. The cross line between this plain and uniform graininess space is calculated as shown in Fig. 6. Although the graininess of the original image decreased due to lower the maximum luminance value, it is possible to give the appearance for graininess equal to that of the original image by changing the physical parameters and returning to this cross line. Therefore, we selected three positions which are A = 232 and S = 4, A = 179 and S = 3, and A = 126 and

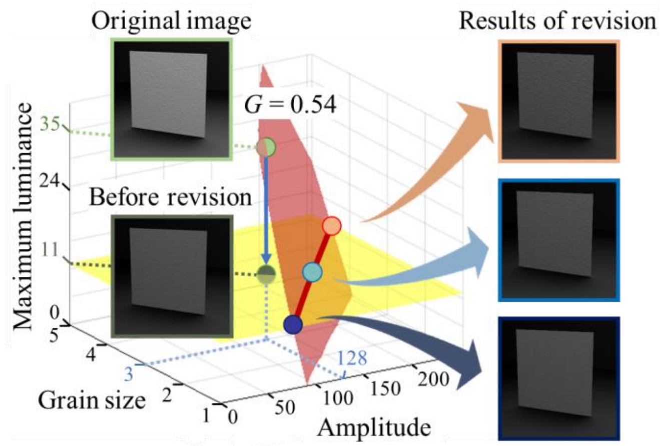


Figure 6 Schematic process of revising graininess G = 0.54

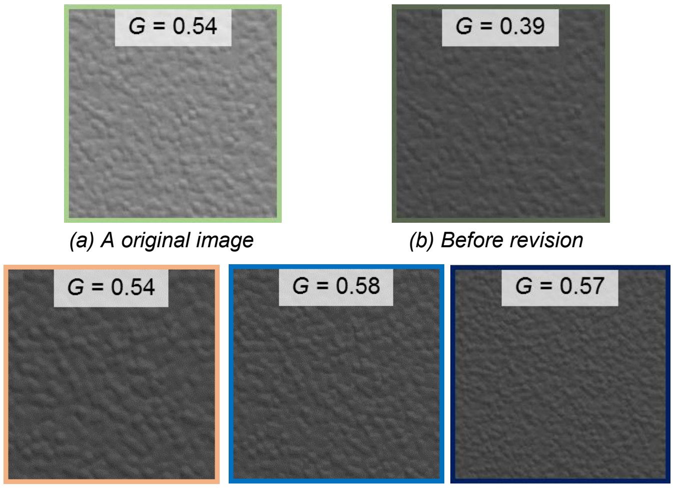
S = 2 on the equal graininess surface in G = 0.54. The three right images of Figure 6 show the results of revision according to our operation. It is clear that our proposed operation is effective to improve the graininess perception of the object even if the luminance of display is different from the original display.

To evaluate whether the graininess of the revised objects was equal to graininess of the original object, we conducted the magnitude estimation with the same condition in the chapter 3. The evaluation score obtained in this experiment were normalized and averaged. As the result, the evaluation score were G = 0.54, G = 0.58, and 0.57, respectively. As the result, it is obvious that the change of depth for ruggedness A is more appreciate to generate the equal perception for graininess compared with the change of size of grain S.

4.2. Evaluation for the Accuracy

The evaluation score of graininess obtained by the magnitude estimation is uneven because this subjective evaluation is hard to compare under different luminance condition. It is necessary to check whether the numerical difference of the evaluation score (G = 0.54 ~ 0.58) for the revised image is appropriate as the revision result. Therefore, we consider the variance in the evaluation score of graininess, and determine this acceptable range. A standard deviation was calculated from the evaluation score of graininess for 27 image used in the magnitude estimation on each subject. The result was 0.12 as an average of standard deviations (SD_{ave}) on each graininess object. Since SD_{ave} is the average of standard deviation in evaluation scores for graininess, it is obvious that the difference of the evaluation score for the revised image is inappropriate if the difference of the evaluation score is more than 0.12. In this revision, since the target graininess of the image after revision was G = 0.54, it was possible to accept the average evaluation in the range of 0.42 to 0.66 which is 0.54 of ±0.12. Therefore, the graininess acceptable boundary is SD_{ave} or less in this paper.

The graininess of the image after revision was from G = 0.54 to 0.58 as shown in Fig 7(c), (d), and (e). Since this evaluation value was a difference of 0.04 at most in comparison to the target value of 0.54, it was sufficiently lower than 0.12 which was the graininess acceptable boundary. This result derives the evidence that our proposed method for uniform graininess space is useful to



(a) A original image *(b) Before revision*

(c) After revision : example 1 *(d) After revision : example 2* *(e) After revision : example 3*

Figure 7 A comparison of revision results by using the model

match the perception of graininess even if the maximum luminance of display is changed.

5. Conclusion and Future works

In this paper, we produced a psychophysically-based model of graininess perception for device independent graininess reproduction model. This model was used to match the graininess perception under the displays with various maximum luminance. The generated objects for the same graininess along this model were observed as the equal appearance with high accuracy.

Unfortunately, this model is evaluated in the only cases that the graininess object has a limited amount of luminance. The limitation of our model should be explored by the additional evaluation. Moreover, our model is only evaluated by using the object of plane surface. There are many kind of objects with complex shape in the world. In our future tasks, it is necessary to achieve the more practical scale implement of appearance matching for the progress of electronic commerce.

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