Reproduction of Depth of Scene in Some Kinds of Printing

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Abstract

We are investigating important physical factors in a display of extra high-quality images. To observe images deeply focusing on the quality of the image reproduction, which is represented by "image depth" or other high-order assessment words, is the best way to find unknown or overlooked factors.

This research report was motivated by observing that when a printed photographic transparency film was observed on white photographic paper, the depth of scene reproduced by it looked greater than that reproduced by normal printing or photograph.

One of the reasons why such first impression was obtained would be due to the good reproduction of black, which occurs because illuminating light goes through a transparency film twice before reaching the eye. For investigating other factors related to the perceived image depth, we removed the difference of the tone characteristics by using a look up table.

The result of the assessment test showed that a combination of internal and surficial reflections of light would enlarge the perceived sensation of "image depth".

We will introduce other methods that would have the good reproduction of "image depth" as in the case of a transparency film on paper.

Introduction

We have been investigating physical characteristics that are important to reproduce extra high-quality images on electronic display. For finding unknown or overlooked physical factors, to observe displayed-images deeply focusing on the quality of the image reproduction, which can be represented by several high-order assessment words, is the best way. This inductive method is necessary to improve the quality of an imaging system, and by now several overlooked important physical characteristics have been found especially on CRT.[1,2]

The assessment words used in our research represent higher-level quality of images than normal quality. Normal quality means the quality that is represented by such as "sharpness" or "colorfulness", which is related more strongly to physical factors.

From the beginning of our research, "image depth" has been one of several important assessment words.[1,3]

In this paper, we will investigate some kinds of printing and methods, which can reproduce or produce the sensation of "image depth". The stereophonic visions using binocular parallax will not be referred to. This report was first motivated by the following observation.

"When we put a printed photographic transparency film on white photographic paper and observe it, the reproduced sensation of "image depth" of it looks greater than that of normal printing or photograph"

First, we will conduct measurement of one of the important physical factors, or the tone characteristics, for two kinds of printing. Secondly, we will remove the difference of the tone characteristics between them by using a look up table. Thirdly, we will report the result of the assessment test. Finally, we will discuss the reason why such first impression was obtained. We will also introduce similar examples that would enlarge the sensation of "image depth".

Tone Characteristics

We printed a gray-scale chart on two kinds of photographic sheets. This gray-scale chart consists of 9 gray levels as shown in Table 1. Both of them were printed by FUJIFILM Pictrography 3000. One is a photographic transparency film (product name: PG-TP) and a printed one will be referred to as **OHP**. The other is normal photographic paper (PG-SG) and printed one will be referred to as **PAPER**. OHP is always put on non-printed white paper (PG-SG) when it is observed and measured.

As the curve of the tone reproduction on OHP looked apparently going down deeper than that on PAPER, CIE tristimulus values Y of 9 gray levels were measured using GretagMacbeth Spectlino colorimeter. The result of the measurements is shown in Table 1 and Fig.1.

Black & Contrast

As shown in Table.1 and Fig.1, the absolute black at digital count of 0 on OHP (=0.5283) is darker than that on PAPER (=0.6341). But because of the lower reflectance of absolute white at digital count of 255 on OHP, the contrast ratio of OHP (= 67.37/ 0.5283=127.5) is almost equal to that of PAPER (= 79.43/ 0.63=126.0).

Table 1. Measured Y Values of the Gray Scale Chart

Digital Count	Y (OHP)	Y (PAPER)
0	0.5283	0.6341
32	0.6147	1.2709
64	0.9288	3.9943
96	1.8732	9.6155
128	4.3289	17.8374
160	10.2731	28.501
192	22.8869	41.4548
224	45.6076	59.3242
255	67.3733	79.4327

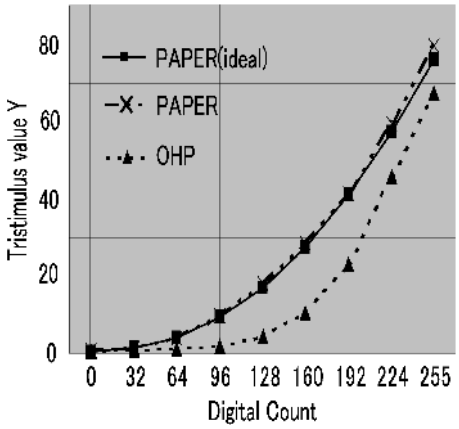

Figure 1. Measured Y values of the gray scale chart

Approximation by General Function Models

The measured tone characteristics of PAPER was almost in agreement with the ideal function given in following equation.

$$Y' = (10^{(2-D_{\min})} - 10^{(2-D_{\max})})(\frac{i}{255})^{\gamma} + 10^{(2-D\max)} \quad (1)$$

where i is a digital count, $D_{\min} = 0.12$, $D_{\max} = 2.3$ and $\gamma = 2.2$.

And then, we used this ideal function as the tone characteristics of PAPER instead of using measured values.

We characterized the non-linear relationship between digital counts and tristimulus values Y on OHP. In order to be compared with the PAPER's ideal characteristics (Eq.1), the GGO model was used to characterize it instead of using the GOG model.[4,5] The GGO and GOG model both have three parameters, which are gain *a* offset *b* and gamma γ, as described by the following equations.

$$GOG\ model:\ Y(i) = Y(255)\left(a\left(\frac{i}{255}\right) + b\right)^{\gamma} \quad (2)$$

$$GGO\ model:\ Y(i) = Y(255)\left(a\left(\frac{i}{255}\right)^{\gamma} + b\right) \quad (3)$$

The three parameters of *a, b* and γ were estimated using 9 measured values (all measured values in Table 1) and the downhill simplex method. The downhill simplex method is one of several useful ways to find optimal values that minimize a given objective function [6]. In the above case, the mean square error (MSE) was given as an objective function.

$$E = \sum_{0}^{255} \left(Y_{act}(i) - Y_{GGO}(i)\right)^2$$

where $Y_{act}(i)$ is a measured value at digital count of i and $Y_{GGO}(i)$ is an estimated value by the GGO model at digital count of i.

The estimated three values were (1.0048, -0.0048, 3.68) for the case $a + b = 1$ and (1.0052, 0.00087, 3.75) for the case that a and b were decided independently. Comparing the gamma value γ between PAPER and OHP, the gamma of OHP (=3.7) was more than one and a half times as much as that of PAPER (=2.2).

This large difference of gamma between OHP and PAPER would be caused because illuminating light goes through a transparency film twice before reaching the eye. According to this reason, if the reflectance of each gray-level on PAPER and the transmittance of each gray-level on OHP are equal, and if the tone characteristics is represented by the simple model: $Y(i) = i^{\gamma}$,[5] the gamma of OHP will be theoretically twice as much as that of PAPER (actually the reflectance of white paper is not 100%, this isn't right).

Our objective of this study is not investigating the influence of the tone characteristics on perceived "image depth", but the influence of the difference of printing on percieved "image depth". For more fair assessments, the difference of the tone characteristics must be removed. We made a look up table to remove the difference of the tone characteristics.

Making of LUT

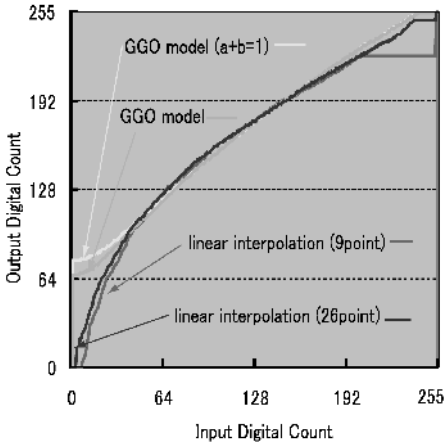

Figure 2. 4 kinds of Look UpTtables

For making a look up table, the function approximated by the GGO model can't be used. An error between an estimated value and an actual value at digital count of 0 is

very large because of significant offset value at digital count of 0 (an actual value of Y(0) is about 0.52 on OHP). Therefore, linear interpolated data using 26 measured values (at digital count of 0,10,20…250,255) was used to make a look up table. The 4 kinds of look up tables made are shown in Figure.2.

These are look up tables which convert the tone characteristics of OHP to that of PAPER. Except for the linear interpolation using 26 points, curves have distortion in low or high digital count range (though the larger the number of measured points, the smoother and better the result is expected to be, 26 points would be sufficient).

Assessment Test

Arrangement and Assessment Words

We used one image printed in black and white (see Figure 3) and prepared 4 types of structures as described below and in Figure 4.

Structure (A) PAPER
Structure (B) PAPER and a transparency film on top of it
Structure (C) OHP
Structure (D) OHP and a transparency film beneath it.

The digital data used for PAPER was converted by the look up table to remove the difference of the tone characteristics in advance.

The assessment words used are "vividness", "image-depth", "brilliance" and "preference". "Vividness" is used to assess whether the details of the image can be seen clearly. We use "vividness" for representing different quality from "sharpness" ("sharpness" sometimes represents enhanced contours or images). "Image depth" is used to assess which image looks not flat but more stereoscopic.

"Vividness", "image depth" and "good reproduction of tone (black)" are the most important three key terms in our research.[2] "Brilliance" means a metallic luster and was selected as an assessment word because it seems to be the most appropriate word to assess the image of Fig. 3. The last assessment word of "preference" was used only to know which image is the most favorite.

Figure 3. An image used in the assessment test

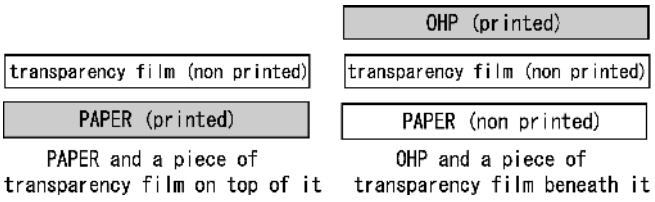

Figure 4 Structures of assessed image

Result of the Assessment Test

The result of the assessment test is shown in Table.2. In this Table, each number represents a mean ranking for each assessment word, and then a smaller number means a better assessment. As for "preference", only no.1 was chosen and chosen percentages are described.

Table 2. Mean Ranking for 4 Structures

	Vivid ness	Image depth	Brillia nce	Prefere nce
(A)	1	4	1.67	-
(B)	2	2.33	3	-
(C)	3	2	1.67	100%
(D)	4	1.67	3.67	-

Table 4 gives us three important results as following.

(1) As for the reproduction of "vividness", PAPER with no transparency film (structure (A)) is the best.
(2) Structure (A), which has the best reproduction of "vividness", is assessed to have the worst reproduction of "image depth".
(3) Some evaluators have the stronger sensation of "image depth" on structure (D) than on structure (C).

The result of (1) is not interesting because it seems to be a natural obtained result because original printed-resolution of PAPER is better than that of OHP (This would occur because of the difference of printing process). In addition, because illuminating light goes through the same part of a transparency film twice in the case of OHP, the reproduction of "vividness" deteriorates naturally.

The result of (2) is very interesting. This shows that "vividness" has no direct relation with "image depth" and the sensation of "image depth" must be enlarged by factors other than the tone reproduction and resolution. The result of (3) gives us a good hint about the physical factors that would enlarge the sensation of "image depth".

Discussion

In this section, we will discuss the reason why OHP produces the more strong sensation of "image depth".

Color Reproduction in Photographic Paper and Films

Photographic paper and transparency films both have a yellow-dye layer, a magenta-dye layer and cyan-dye layer.[7] If all layers are exposed, it looks black and if all layers essentially unexposed, it looks white. The excellent

reproduction of the tone and deep colors would be due to the multi-layer reflections caused by the existence of these 3 layers. This factor has no relation with the difference of percieved "image depth" between OHP and PAPER.

Reflections on Several Surfaces

In the case of OHP (structure C in the assessment test), there would be two kinds of reflections of illuminating light. One is the reflection on the surface of OHP. The other is the reflection in the interior of OHP, or on the surface of paper. If another one transparency film is inserted between OHP and paper (structure D), it will cause another one reflection.

Though a combination of these reflections on the multi-surface apparently deteriorates the quality of "vividness", this process would enlarge the sensation of image depth.

Effect of Scattering of Light

On the surface of normal photographic paper, specular reflection is considered to be a main element, and then the image printed on paper would look clear but flat. The multi-surface reflections in the case of OHP would cause the scattering of light, and this scattering of light might play a role of pseud-air layer and consequently we might have the strong sensation of "image depth".

Other Methods

In this section, we will introduce some examples that would produce the sensation of "image depth" because of a combination of speclar reflection at the surface and diffuse reflection inside it. The stereophonic visions with using binocular parallax will not be referred to here.

Oil Painting

Oil painting consists of layers including clear paint and unclear paint. This causes complicated reflections of illuminating light at the surface and in the interior of painting, and consequently would produce a depth of images. In oil paintings, in order to compress 3-demensional real world into a 2-demensional campus, clear oil paints are used to construct pseudo-air-layer on a campus. This pseud-air-layer is considered to play a role of enlarging the sensation of "image depth".

Electronic Aquarium

Electronic aquarium has a real aquarium in front of an electronic display. The existence of real water would cause the scattering of light that reaches the eye, and consequently our brain would perceives pseud-image-depth.

Human Skin

On human skin, specular reflection occurs on the surface of skin and diffuse reflection occurs in the interior of skin. The element of specular reflection has information of an unevenness of skin. On the other hand, the element of diffuse reflection has information of color of skin. This combination of two reflections would produce the good texture and deep color of skin.

Conclusion

This research report was motivated by observing that when a printed transparency film was observed on white paper, the depth of scene reproduced by it looked greater than that reproduced by normal printing or photograph.

This first impression would be due to:

1. the good reproduction of black on OHP
2. a combination of surficial and internal reflections
3. scattering of light caused through a complicated path.

We will have to discuss the reason why these physical factors would enlarge the sensation of "image depth" and also the relation between the reproduction of "vividness" and "image depth" in more detail.

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References

1. Makoto Miyahara et al, *Important Factors to Convey High Order Sensation,* IEICE TRANS.COMMUN., vol.E81-B, no.11, pp. 1996-1973 (1998).
2. Makoto Miyahara, *The Newly Extra High Quality Imaging System can Display both merits of Printing and Electric Imaging,* NIP17-93, (2001)
3. Masashi Kameda et al, *Quality evaluation of extra high quality images based on key assessment word*, IS&T/SPIE, EI'01, vol. 4299, pp. 593-601 (2001)
4. Roy S Berns, *Methods for characterizing CRT displays*, Displays, vol.16, no.4, pp173-182 (1996).
5. Tatsuya Deguchi et al, *The Effect of User Controls on CRT Monitor Characteristics*, SPIE Vol.3300, pp. 219-230.
6. William H. Press et al, *Numerical recipes in C: the art of scientific computing*, Cambridge University Press (1997)
7. Edward J.Giorgianni et al, Digital Color Management, Addison Wesley, pp. 460-472 (1998)

Biography

Hideki Shirai received his B.S degree in electrical engineering from the Tokyo Institute of Technology in 1997 and master's degree in Information Science from Japan Advanced Institute of Science and Technology (JAIST) in 1999. Since 1999 he has been doctoral student in JAIST. His interested topics are high quality image reproduction, image processing and color science.