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# A Consideration on "Sweetness" by 3D CG with Fruits as an Example

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***Abstract*: *Today, there are a lot of images and videos drawn by 3D computer graphics (hereinafter referred to as 3DCG) around us, and 3DCG is permeating our lives [1]. Recently, research and development of 3DCG-related technologies such as 3D printers, AR, and VR have been actively carried out, and further progress in 3DCG can be expected in the future. 3DCG is a technology that creates images and videos by creating objects in a virtual three-dimensional space. CAD, VR, AR, simulators, 3D printers, etc. have been developed as technologies that apply this. One of the reasons why it was applied to such technology is the high expressiveness of 3DCG. It is possible to express various substances such as wood, metal, plastic, and glass, and it is becoming possible to reproduce things that do not have a specific shape, such as flames, smoke, and fluids. One of the researches on such 3DCG technology is digital food, and research is being conducted with the aim of putting it into practical use in the future. Digital food is expected to solve problems related to food freshness management, disposal, new product development simulation, etc., but even with the expressive power of 3DCG, meat and fish are still difficult. I am not good at expressing fresh foods such as vegetables and fruits, and "freshness" and "organic coloring" such as "fresh flowers". This is one of the issues that cannot be avoided even in the research and development of digital foods and must be solved. In this technology, while understanding the principle of 3DCG, I learned using some software in order to explore what technology is necessary to create a digital food. Also, in learning, we set the goal of "expressing fresh fruits", which is one of the challenges of digital food, and the gloss of the skin peculiar to fruits, the slight unevenness of the surface, especially the freshness of the cut surface of fruits we focused on reproducing the expression of freshness.***

***Keywords: Computer graphics, Ambient light, Specular reflection light, Diffuse reflected light, Subsurface scattering, Fresnel formula***

## I. INTRODUCTION

Today, there are a lot of images and videos drawn in 3D computer graphics (hereinafter 3DCG) around us, and 3DCG is permeating our lives1) [1]. Recently, research and development of 3DCG-related technologies such as 3D printers, AR, and VR have been actively conducted, and further progress of 3DCG can be expected in the future. 3DCG is a technology that creates an image or video by creating an object in a virtual three-dimensional space. CAD, VR, AR, simulators, 3D printers, etc. have been developed as technologies that apply this. One of the reasons why it was applied to such technology is the high expressive power of 3DCG. Various materials such as wood, metal, plastic, and glass can be expressed, and things that do not have a specific shape such as flames, smoke, and fluids are becoming reproducible. One of the researches on such 3DCG technology is digital food, and digital food, which is being researched for practical application in the future, has problems related to food freshness control, waste disposal, simulation of new product development, etc. Although it is expected to be solved, the expression of fresh foods such as meat/fish, vegetables/fruits, and fresh flowers is still difficult even with the expressive power of 3DCG. 3DCG is not good at expressing the "freshness" and "organic coloring" of fresh foods and flowers. This is one of the problems that must be solved and cannot be avoided in the research and development of digital food. In this research, I learned about the principles of 3DCG and used some software to study what technology is needed to create a digital food. In learning, aiming at "refreshing fruit expression", which is one of the challenges of digital food, the luster of the skin peculiar to the fruit, the fine irregularities of the surface, especially the freshness of the cut surface of the fruit I focused on reproducing the expression.

## II. PRPARATION FOR STUDY

### A. Ambient light

Ambient [1] light is one of the elements for setting the material in the 3DCG model. It gives a certain amount of brightness to the whole scene, and is used when simply expressing indirect light generated by reflection of light between objects or inside an object. In the 3DCG space, it has the effect of preventing the part that is not directly exposed to light from becoming completely black.

### B. Specular reflected light

Specular reflection (regular reflection) [2] is one of the elements for setting the material in the 3DCG model. Light that hits the surface of the model completely is reflected, and light from one direction is reflected in another direction and goes out. It often occurs on mirrors and shiny metal surfaces.

### C. Diffuse reflection

Diffuse reflected light [3] is one of the elements for setting the material in the 3DCG model. It refers to light that uniformly diffuses into a hemisphere by simplifying the reflection of light that hits the surface of the model.

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Reflection of a general substance includes both specular reflection and diffuse reflection components. Generally, a substance having a higher reflectance has a larger specular reflection component.

### D. Material judgment

Material setting is the work of defining the color of the modeled object, the reflectance of light, the transmittance of light, the refractive index of light, etc., and the information of the property showing the color, semi-transparency and freshness of the object. To decide.

### E. Subsurface scattering

Subsurface scattering [4] is a phenomenon that occurs in semitransparent substances such as skin and fruits, and is a phenomenon in which light enters and scatters inside an object. In surface scattering, light entering a point xi on the surface of an object is reflected once or multiple times inside the object and emerges from another point xo.

### F. Participating media

Participating media [5] refers to an area in which the ratio of light absorption/scattering by fine particles in the area is high. A material such as a semi-transparent material that has a large light scattering or absorption ratio in a region is treated as a participant medium. In this type of media rendering, the degree of scattering and absorption are controlled by the scattering coefficient and the absorption coefficient. In addition, the phase function represents the characteristic of how much the light is scattered forward or backward as viewed from the incident angle. For the phase function, the Henyey-Greenstein function (L. G. Henyey, 1941) is used with the average value g of the angle formed by the incident direction and the scattering direction as a parameter. g is the value obtained by integrating the product of the cosine of the angle formed by the incident direction and the direction of confusion and the phase function 6) on the entire spherical surface.

### G. Fresnel formula

The Fresnel's equation [6] is an equation that describes the behavior (reflection/refraction) of light at the interface. It is possible to calculate how much of the energy of incident light is reflected and how much is transmitted, at the boundary between media having different refractive indices. The Fresnel equation is expressed as follows.

$$t_p = \frac{2n_A\cos\alpha}{n_B\cos\alpha + n_A\cos\beta} = \frac{2\sin\beta\cos\alpha}{\sin(\alpha+\beta)\cos(\alpha-\beta)}$$
$$r_p = \frac{n_B\cos\alpha - n_A\cos\beta}{n_B\cos\alpha + n_A\cos\beta} = \frac{\tan(\alpha-\beta)}{\tan(\alpha+\beta)}$$
$$t_s = \frac{2n_A\cos\alpha}{n_A\cos\alpha + n_B\cos\beta} = \frac{2\sin\beta\cos\alpha}{\sin(\alpha+\beta)}$$
$$r_s = \frac{n_A\cos\alpha - n_B\cos\beta}{n_A\cos\alpha + n_B\cos\beta} = -\frac{\sin(\alpha-\beta)}{\sin(\alpha+\beta)} \qquad (1)$$

In the Fresnel equation, $t_p$ and $t_s$ are amplitude transmittances of p-polarized light and s-polarized light, respectively, and $r_p$ and $r_s$ are amplitude reflectances of p-polarized light and s-polarized light, respectively. The Fresnel's equation regarding the energy transmittance T is obtained from the square of the amplitude. The energy reflectance and energy transmittance are shown below.

$$T_s = \frac{n_B\cos\beta}{n_A\cos\alpha}t_s^2, T_p = \frac{\tan\alpha}{\tan\beta}t_p^2$$
$$R_s = r_s^2, R_p = r_p^2 \qquad (2)$$

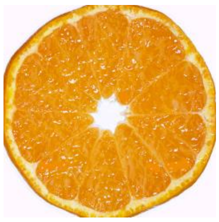
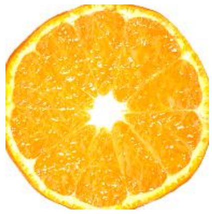
## III. FRESH FRUIT EZPRESSION

In order to make the cut surface of fruit fresh, it is necessary to express the characteristics of the cut surface as shown in Table- I (a) (see Table- I).

A major feature of the cut surface is

- Wet with juice
- There are fine irregularities due to the cell wall that remains after the juice overflows
- There are three points that the flesh is transparent.

**Table- I: Comparative image of orange.**

| (a). Real image. | (b). Parameter settings for POV Ray. |
|---|---|
|  |  |

This is a characteristic common to many objects, although there are differences in water content depending on the object and its site. Table- I (b) shows the parameters adjusted in POV-Ray. The parameters used here are ambient: 0.60, diffuse: 1.00, specular: 1.00, brilliance: 0.60, roughness: 0.01, ior: 1.33. These parameters are elements of light in CG, and are parameters that define the material settings from the top such as ambient light, diffuse reflection light, specular reflection light, gloss, surface roughness, and refractive index. The image in Table- I (b) is not sufficient for expressing freshness, but compared to Table- I (a), it showed a function of feeling freshness in expressing freshness and water.

## IV. MODELING FRUIT CROSS SECTIONS

In this study, it is considered that the juice cross section is composed of air, juice and pulp. It is assumed that the juice layer is sufficiently thin compared to the air layer and the pulp layer so that scattering does not occur in the juice layer. It is also considered that the transmitted light in the juice layer and the subsurface scattered light in the pulp layer reach the pulp layer and the air as they are. Light incident on the pulp is scattered by the pulp layer and then emitted from a position different from the incident point. Fig. 2 shows the fruit cutting model proposed in this study (see Fig. 2).

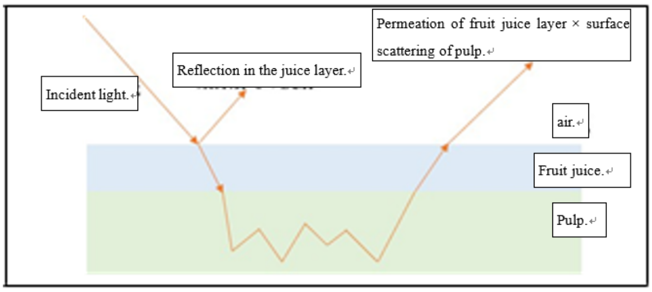



**Fig. 2. Proposed fruit cross-section model.**

From Fig. 2, the radiance of the surface can be obtained by adding the propagation radiance considering the transmission to the inside of the object and the reflected radiance considering the reflection on the liquid surface.

### A. Transmission model

In the transmission model, the amount of light transmitted through the juice layer is determined. When the refractive indices of air and juice are $n_1$ and $n_2$, respectively, and the incident light is $\omega_i$, the amount of transmission $I_t$ is the equation (3).

$$I_t = I_L * \left\{1 - \frac{1}{2} F_r(\vec{\omega_i}, n_1, n_2)\right\}. \quad (3)$$

It can be expressed as [7]. $I_L$ represents the brightness of incident light, $F_r$ represents Fresnel reflection, and is the average of the energy reflectances of p-polarized light and s-polarized light.

### B. Reflection model

In the reflection model, the amount of light reflected by the juice layer is calculated. In addition, the reflection model will be divided into two types, a diffuse reflection model and a specular reflection model. The reflected radiance can be obtained by adding the intensities of these two lights.

### C. Specular model

In the specular reflection model, the specular reflection coefficient $\rho_s$ is used to express the specular reflection luminance $I_r$ by the following formula.

$$I_r = I_L * \rho_s * F_r(\vec{\omega_i}, n_1, n_2). \quad (4)$$

### D. Diffuse reflectance model

The Lambertian reflection model is used as the diffuse reflection model. Lambertian reflection [8] is a model that ideally handles a diffuse reflection surface. This reflection is calculated by using the inner product of the normalized normal vector N of the surface and the normalized vector L pointing from the surface to the light source, and is multiplied by the brightness of the incident light.

Using the Lambertian reflection model and the diffuse reflection coefficient $\rho_d$, the diffuse reflection brightness $I_d$ is represented by the following formula.

$$I_d = I_L * \rho_d * F_r(\vec{\omega_i}, n_1, n_2) * N * L. \quad (5)$$

## V. SUBSURFACE CONFUSION MODEL

Subsurface scattering can be expressed using a bidirectional scattering surface reflectance function (BSS-RDF). BSSRDF is a function that represents the brightness of light that is incident on a certain point and is scattered inside the object and that is emitted to the outside from a place different from the incident point. It is a function described by the incident position, direction, exit position, and direction on the object surface. In this study, we use the dipole model as a model for subsurface scattering. In this model, $f_{BSSRDF}$ (xi, $\omega_i$, xo, $\omega_o$) can be decomposed as follows by assuming that the internal scattering does not depend on the directions of incident light and emitted light.

$$f_{BSSRDF}(x_i, \vec{\omega_i}, x_0, \vec{\omega_0}) = \frac{1}{\pi} F_t(\eta, \vec{\omega_i}) R_d(x_i, x_0) F_t(\eta, \vec{\omega_0}). \quad (6)$$

Here, $F_t(\eta, \omega_i)$ is the Fresnel's equation when light is transmitted in the angle $\theta$ direction with respect to the boundary surface of the relative refractive index $\eta$. $R_d(x_i, x_o)$ is a scattering term that represents the attenuation of incident light and emitted light between two points separated by a distance $r = \|x_i - x_o\|$ and is approximated by the following equation.

$$R_d(r) = \frac{\alpha}{4\pi}\left\{Z_r\left(\sigma_{tr} + \frac{1}{d_r}\right) * \frac{e^{-\sigma_{tr} d_r}}{d_r^2} + Z_v\left(\sigma_{tr} + \frac{1}{d_v}\right) * \frac{e^{-\sigma_{tr} d_v}}{d_v^2}\right\}. \quad (7)$$

At this time, each variable is given by the following formula.

$$d_r = \sqrt{r^2 * Z_r^2}, d_r = \sqrt{r^2 + Z_v^2}$$
$$Z_r = \frac{1}{\sigma_t'}, Z_v = Z_r\left(1 + \frac{3}{4}A\right)$$
$$A = \frac{1 + F_{dr}}{1 - F_{dr}}$$
$$F_{dr} = -\frac{1.440}{\eta^2} + \frac{0.710}{\eta} + 0.668 + 0.0636\eta$$
$$\sigma_{tr} = \sqrt{3\sigma_a \sigma_t'}$$
$$\sigma' = \sigma_s' + \sigma_a, \sigma_s' = \sigma_s(1 - g)$$
$$\gamma = \frac{\sigma_s'}{\sigma_t'}. \quad (8)$$

Here, $\sigma_s$ and $\sigma_a$ are parameters called scattering coefficient and absorption coefficient, respectively, and g is a parameter that determines the isotropicity of scattering described in Chapter 2 and four parameters including the relative refractive index $\eta$.

## VI. EXCEUTION RESULT

We used OpenGL and Visual C++ as the implementation environment, and used Stanford Bunny as a preliminary model. As a comparative image, in Table- II (a), materials other than color are not set, and in Table- II (b), this method is used (see Table- II).

**Table- II: The expression result of "freshness".**

| (a). Comparison image. | (b). An image using this method. |
|---|---|
|  |  |

Comparing Table- II (a) and Table- II (b), it can be seen that Table- II (b) can express expressions such as translucency and freshness.

## VII. CONSIDERATION

In this research, we paid attention to the "freshness" of fruits and vegetables, and proposed the expression method. The fruit cross-section model proposed this time uses a simple transmission and reflection model, but I think that it still yielded sufficient results regarding the expression of "freshness". However, since this time we are focusing only on the cut surface, we feel that another method is needed to express the outer skin of the fruit.

## VIII. FUTURE TASKS

By incorporating this method into an interface such as the one in Ref. [1] that interactively generates result images, it is possible to interactively draw fresh fruits and vegetables. In addition, there are various reflection and transmission models that express the surface roughness, and it is thought that they can be brought closer to the real thing by incorporating them. This time, we conducted research focusing on the cut surface [1], but research on more realistic representation of the outer skin of fruits is also underway, and it is thought that it can be reproduced more by combining with them. Also, if we can find the appropriate parameters for each fruit, we think that digital food will be close to the real thing that can be mistaken for a real photo. In the future, it is necessary to advance research in such areas.

## IX. SUMMARY

During the course of this research, I felt that the expression pursuing reality requires not only solving the technical problems of 3DCG, but also devising the manufacturing process of 3DCG. For example, the degree of light reflection and transmission, and the degree of absorption, which I did not consider this time, may also be related. Approximately 50 years have passed since the technology that forms the basis of CG was developed. In the last 50 years, CG technology has grown rapidly, and the technology called 3DCG has been developed. However, there are still many issues to be solved with this technology. In other words, 3DCG is a developing technology that has the potential to continue to advance. In addition, fields such as AR and VR that apply 3DCG are rapidly becoming widespread. Now that new fields have emerged, we can see a different perspective and expect the evolution of new 3DCG technology.

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