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# Projection Mapping for Enhancing the Perceived Deliciousness of Food

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**ABSTRACT** The perceived deliciousness of a food item is highly related to its appearance. Image processing has been widely used to make food images more appealing to the public, such as when capturing and posting images on social networking sites. This paper proposes a methodology and a system to enhance the degree of subjective deliciousness perceived by a person based on the appearance of a real-food item by changing its appearance in a real environment. First, an online questionnaire survey was conducted to analyze the appearance factors that make food look delicious by using various food images. Based on this knowledge, a prototype system, which projects a computer-generated image onto the food item, was constructed for enhancing its subjective degree of deliciousness based on its appearance at a pixel level. Finally, a user study was conducted in which the subjective degree of deliciousness based on the food appearance was compared under various appearance modification conditions. The results show that appropriate chroma and partial-color modifications highly increase this degree of deliciousness, thus implying that the proposed system can successfully be used to improve the appearance of food to make it look more delicious.

**INDEX TERMS** Food, spatial augmented reality, projection mapping.

## I. INTRODUCTION

Eating is one of most fundamental human actions and can considerably affect their quality of life. The sense of satisfaction when a person eats a delicious food item is well known to lead to a sense of happiness [1]. The deliciousness of food is not only related to its taste but also related to a person's cognitive interpretation of the food as an integration of multimodal sensations from its appearance, smell, and tactile sense [2], [3]. Especially, the physical appearance of food is the most important factor for judging its deliciousness besides the taste itself.

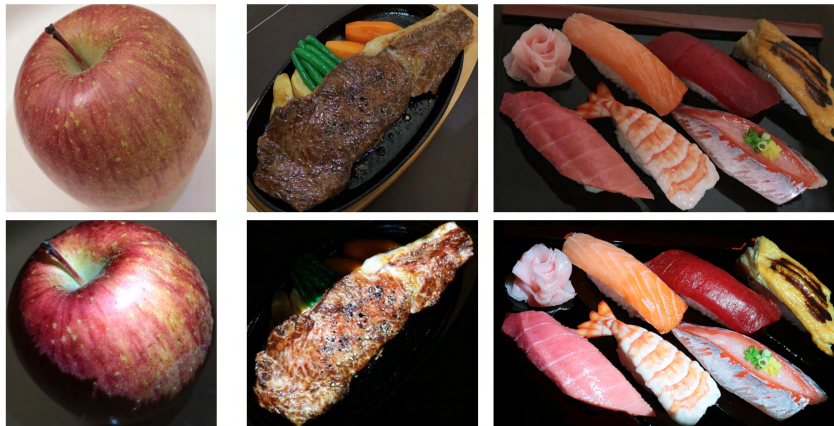
In recent years, the capturing of pictures of food by using smartphone cameras, when eating at a classy restaurant or cooking at home, and sharing them with friends and others through social networking sites has become a common practice. In such cases, "post image processing," in which the color and brightness of the images are adjusted, is often performed to make the food item look more delicious and appealing [4], [5]. The main motivations for this are to enhance the experience, make it more appealing to others, and record such experiences.

In a similar manner, if you can change the appearance of a real food item before eating it, the degree of subjective

deliciousness perceived from the appearance might be improved. This research aimed at proposing a methodology and a system for this purpose, specifically by using a projector-camera system. As a projector can change the brightness or chroma of the projected light on a pixel level, the appearance of a real object can possibly be changed by analyzing the object-image captured using a camera and projecting appropriate light to each location by using a projector.

One of the feasible and direct applications of this technology is to make food (real or sample) look more attractive at displays in shops and restaurants for promotion. Furthermore, in the near future, the author envisions that this technology will enable users to perceive an arbitrary food item to be more delicious while actually eating at home or a restaurant. It would also help users (e.g., children) overcome their particular food aversion [6].

Several studies have been conducted, mainly in the field of psychology, to determine the influence of the appearance of food on the degree of subjective taste and appetite of people. Hasenbeck et al. [7] revealed, through a controlled experiment, that blue light decreases appetite, whereas yellow light increases it. While influences of fundamental changes in such homogeneous colors of ambient light on appetite or taste



**FIGURE 1.** The proposed projection mapping technique makes food look more delicious and appealing in the real world.

elements have been widely researched, not enough research has been conducted on how the subjective deliciousness is affected by intentional inhomogeneous changes of each appearance factor based on the original appearance of the food item.

Therefore, in this research, the degree of subjective deliciousness perceived based on the appearance is defined as “the degree of appearance-based deliciousness (DAD)” and first confirm the influence of each appearance factor on the DAD through a simple questionnaire-based method using food images. Based on the results obtained, a projector-camera system was constructed for controlling the prospective appearance factors of target food and evaluated its effectiveness for our purpose (as shown in Fig. 1). The main contributions of this study are as follows.

The author reveals feasible appearance features of food related to its deliciousness through a questionnaire by using food images based on responses from 55 participants.

Based on the aforementioned knowledge, the author proposes a methodology and a prototype projector-camera system that analyses the appearance of target foods in a simple manner and changes it to increase the DAD in a real environment.

A user study confirmed that changing the appearance factors by using the proposed system in an appropriate manner certainly affects the DAD and the feasibility of controlling it.

## II. RELATED WORK

### A. ANALYSIS OF FOOD APPEARANCE

Attributes, such as taste and attractiveness, that people perceive based on the appearance of food have been studied in the field of psychology for a long time [2], [8]. The lighting of an environment is known influence food consumption. An environment with a warm light source, such as candles, is known to increase the duration of the meal and food consumption [9].

To quantitatively evaluate the appearance of food (e.g., maturity and quality), analytical methodologies based

on sensor information, such as that obtained from spectrophotometers and cameras, have been studied in the field of computer vision and image processing [10], [11]. Takahashi *et al.* [12] developed a method to estimate the attractiveness of a food image by extracting features, such as size, position, shape, and main orientation, of the main ingredients in the image. Murakoshi *et al.* [13] reported that the distribution of luminance of food, especially fish, affects its apparent freshness. Nishiyama *et al.* [14] proposed bags-of-color-patterns to automatically determine the aesthetic quality of general images. This feature describes color harmony of small areas as the shape of a histogram with dominant color differences for each channel of hue-saturation-value (HSV).

### B. AUGMENTED REALITY FOR FOOD

The changing of a target object’s appearance is one of the fundamental concepts of augmented reality (AR) where additional information is superimposed onto the real world. So far, several AR studies using a normal display or a head mounted display (HMD) have been performed to overlay images onto physical food. Narumi *et al.* [15] proposed a system that changes the perceptual taste of target cookies by overlaying a texture image onto the cookie through an HMD, and additionally presenting the smell through air-pressure devices. They also proposed a system that increases a user’s feeling of satiety by increasing the size of the food item he/she is grabbing in AR [16]. However, in spite of the rapid development and spread of HMDs, the habit and culture of wearing HMDs in daily life are not yet widespread, especially during meals; moreover, these HMD-based AR methods impose certain constraints on their uses.

In contrast, a projector-based system was assumed to be more appropriate in this field because restrictions, such as those of wearing special equipment, are not imposed on users. Recently, some studies were conducted on projectors that allow changing the appearance of target food. Husisman *et al.* [17] confirmed the influence of color, background image, speed of the animation, etc., on the perceived

taste factors such as sweetness and sourness. Based on this information, they developed a multimodal system that controls taste factors by changing the color of a target food item such as yogurt [18]. Nishizawa *et al.* [19] also proposed a projector–camera system that changes the subjective sweetness and sourness by the changing the chroma of cakes or chips. Kita and Rekimoto [20] developed a system to influence the quality of an eating experience by providing sounds that affect the food taste (e.g., a crackling sound when meat is cooked) as well as the enhancement of chroma by using a projector–camera system [20].

As described earlier, most existing studies on methodologies and systems for changing the appearance of food mainly targeted the influence of specific primary color changes on the basic factors of food taste (sweet, hot, salty, bitter, etc.) or flavor. Few studies have revealed how subjective deliciousness, visually perceived by people, is influenced by actually changing each appearance factor of the food item in the real world. In this study, the author focused on this point and first explored the prospective appearance factors among various other factors that can be changed arbitrarily based on previous research.

### III. EFFECT OF APPEARANCE FACTORS ON THE DAD

A simple web-based questionnaire survey was conducted to ascertain the relationship between the DAD and each appearance factor.

#### A. APPEARANCE FACTORS

First, the following factors were considered based on existing studies that can possibly affect the DAD.

##### 1) CHROMA

The chroma of the color of food surface is an important factor to judge the food quality. For example, for some fruits, high chroma value represents their maturity and sweetness. In contrast, fruits with low chroma look sour. Furthermore, some foods, such a beef, with low chroma are known to appear stale (i.e., not fresh) [21].

##### 2) HIGHLIGHT

Among all the reflected lights on the target food surface, the specular factor is considered as the highlight region. Highlights represent the glaze on the food surface and indicate the perceptual freshness and juiciness of food [22]. For example, Nakai *et al.* [23] revealed that the projection of fluctuating light onto the eye of fish improves the subjective freshness perceived from its appearance.

##### 3) PARTIAL COLOR MODIFICATION

The inhomogeneous color of each partial region and the homogeneous color of the entire region of food have also been used for judging the food taste. For example, for fruits, partial color and their chroma are important factors for judging their maturity [24]. The existence of green regions shows the degree of maturity in the case of apples. For beef, the balance

between the red region (indicating muscle) and the white region (indicating fat) is important for judging its taste.

##### 4) WETNESS

The moderate wetness of an object was assumed to be an indicator representing the freshness of vegetables and fruits that are washed before eating.

#### B. TARGET FOOD

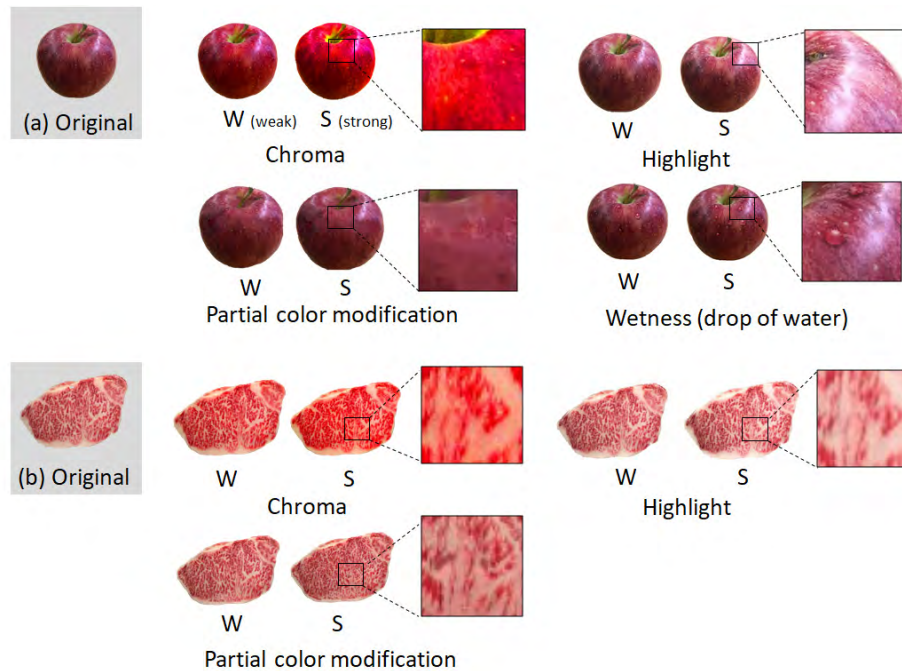
Most actual meals consist of several dishes, and each dish is made of multiple ingredients. As a first step, however, a single ingredient was used as the experimental target to exclude complex factors. An apple was considered as an example from the Vegetable/Fruit category and raw beef as an example from the Meat category; the images for these were obtained from the École Polytechnique Fédérale de Lausanne (EPFL) food image dataset, in which various foods are classified into 11 types [25]. The image processing of each appearance factor was performed for two original images of apple and beef. Each of the four factors including chroma, highlights, partial color modification, and wetness was modified in two stages for the apple image; therefore, a total of nine images [one original + four factors × two conditions (one for each stage)] were used. For beef, the wetness factor was omitted because beef with a wet surface was assumed to be unnatural. Thus, each of the three factors was modified in two stages for the beef image. Furthermore, a dummy image that was exactly same as the original image was added for one of the conditions to check the reliability of participants' responses; therefore, a total of eight images (one original + three factors × two conditions + one dummy) were used. Each modified image for both apple and beef is illustrated in Fig. 2.

#### C. PROCEDURE

An online form with 16 images was prepared, as shown in Fig. 2. For each image, participants were asked to view the images on their own PC monitors (which were not color-calibrated) and provide subjective deliciousness scores by responding to the following question: “How delicious do you think the food in the image looks (1: Not at all, 3: Neutral, 5: Very much)?”. The order of the displayed images was randomized for each target food. The participants were 55 university students (aged: 18–21) and all of them participated voluntarily in this experiment through the online survey. Among them, two participants evaluated the dummy image with a score that differed by a value of 2 or more compared to the score of the same-condition image. All scores from those two participants were regarded as low reliability and were excluded from the following analysis.

#### D. RESULTS

Fig. 3 illustrates the distribution of the DAD for each image. A *t*-test was conducted with Bonferroni correction between each image and the original image, regarding the DAD as the order scale. The results show that only highlight conditions



**FIGURE 2.** Images used for evaluation: (a) apple and (b) beef images.

had a significant positive effect on the apple image (original / weak highlight:  $p < 0.05$ , original / strong highlight:  $p < 0.01$ ). Partial color modification and chroma enhancement negatively affected the DAD. Furthermore, for the beef image, there were several significant negative effects due to chroma enhancement.

Moreover, in terms of the ratio in which the DAD is higher than 3, i.e., the ratio representing some positive feeling, the ratios of chroma (weak), highlight (weak and strong), and wetness (weak) for the case of apple increased compared to those of the original image. In the case of beef, ratios of only highlight (weak) and partial color modification (weak) increased.

### E. DISCUSSION

The above results show that the difference between the modified image and appearance of the target food perceived by participants caused a significant negative effect on the DAD. For example, the excessive chroma enhancement for the apple image, which made it look unnatural (Fig. 2), significantly reduced the DAD. Conversely, highlight has a certain effect on both apple and beef. Unlike water drops (wetness), highlights are potentially observed on the surface of various foods in the real world. Thus, it can be assumed that it was not perceived to be unnatural by the participants, and it contributed toward representing freshness.

Although no positive effects of chroma enhancement were observed in this evaluation, the chroma of food image can be predicted to be highly related to the DAD because it had significant negative effects on the images of both apple and beef. The chroma enhancement in this experiment might have

been excessive, as shown in Fig. 2, and careful modification to achieve the appropriate degree of enhancement may have a positive effect.

A general analysis cannot be conducted based on these results; however, the appearance factor that did not have any significant effect ( $p < 0.01$ ), namely, wetness, was disregarded. Moreover, as described earlier, as factors that were observed to have a negative effect may potentially have positive effects depending on the control method or degree, they were included in the following system functions in addition to the factors that showed positive effects.

## IV. SYSTEM CONSTRUCTION

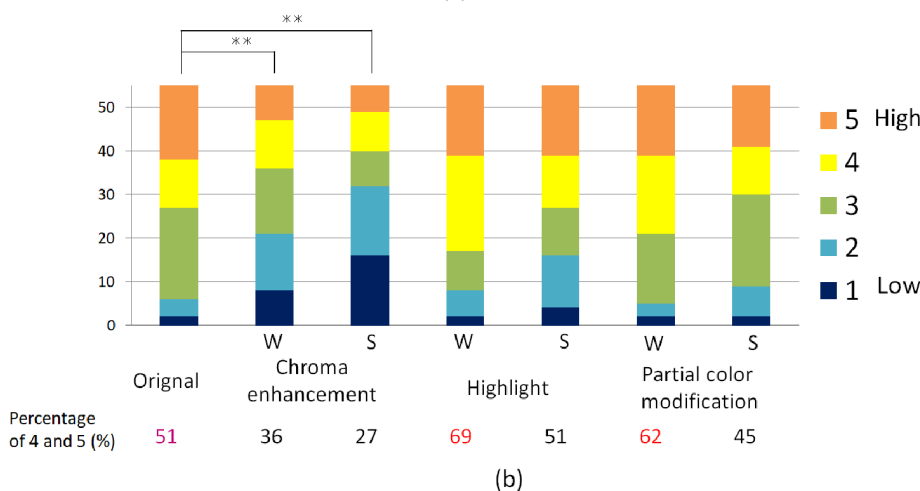
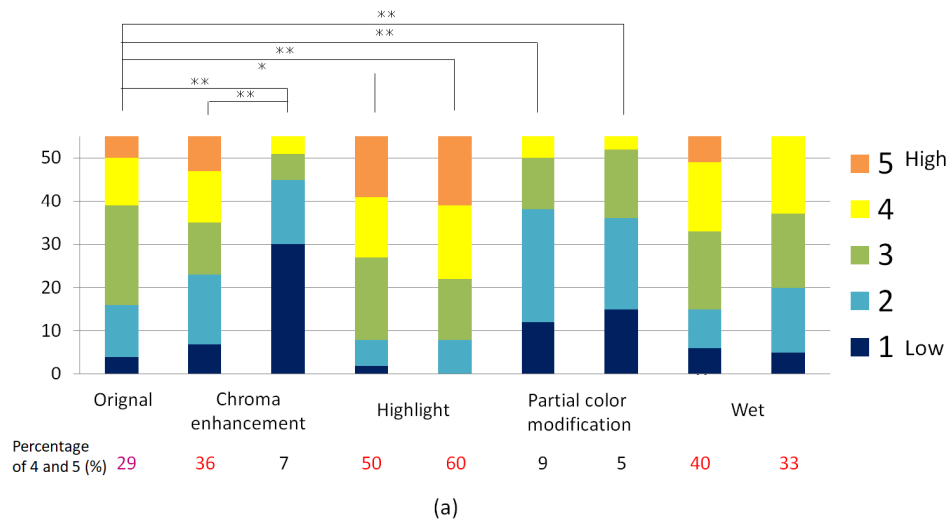
A prototype system was developed that changes the appearance of target foods for increasing the DAD.

### A. HARDWARE CONFIGURATION

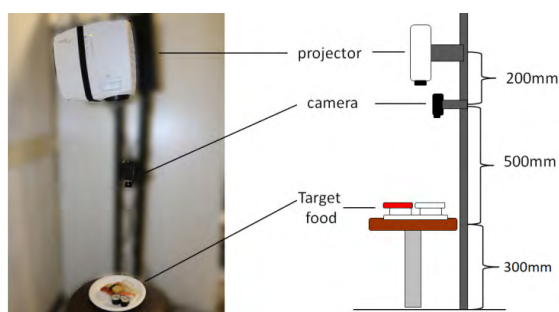
Fig. 4 illustrates the device configuration of the system, which consists of a PC (CPU: Intel Core i7-4712 2.3 GHz, RAM: 16 GB, GPU: NVIDIA Quadro K1100M), a camera (Point Grey Grasshopper3 GS3-U3-23S6, resolution:  $1920 \times 1200$  pixels), and a digital light-processing projector (Optoma Inc. HD37, resolution:  $1600 \times 900$  pixels). The light axes of the projector and camera are almost parallel to the normal of the floor and face downward, i.e., they face the target object. A user was assumed to observe the target from an angle at the top similar to that of the camera.

### B. ALGORITHM

Fig. 5 shows the overview of the algorithm. For the pre-processing, food region extraction and highlight analysis

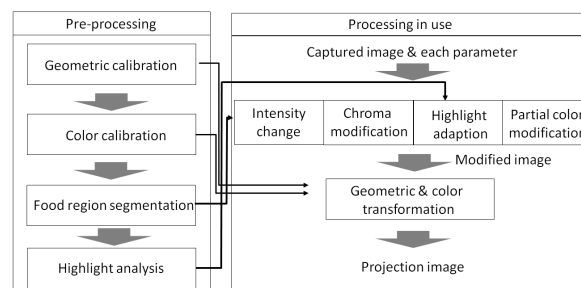


**FIGURE 3. Questionnaire results on how each appearance feature influences the subjective degree of appearance-based deliciousness (DAD) for (left) apple image and (right) beef image (\*:  $p < 0.05$ , \*\*:  $p < 0.01$ ).**



**FIGURE 4. Device configuration of the system.**

(described in the following subsections) were performed along with the geometric and photometric (color) calibrations between the projector and camera. During the actual use, each appearance factor for the original image acquired by the camera is modified based on the corresponding parameters, indicating the degree of each modification obtained from



**FIGURE 5. Process flow.**

the user. The system has three parameters, that is, chroma, highlight, and partial color modification, to control each appearance factor, as discussed in the previous section and two additional parameters to control the intensity only on the food and nonfood regions; this is the same as changing the normal environmental light as a baseline. From the modified

camera image, an image to be projected is generated using the geometric and color transformation information during precalibration. These processes are repeated every time a new parameter is obtained from the user.

### 1) CALIBRATION

Although it is desirable to appropriately change the image to be projected depending on the observable shape changes of the target food during the meal, I assume that the system would be used before eating, and thus do not consider the changes during this time. The relationship between each pixel of a camera image  $I_c$  and projector image  $I_p$  is acquired by the gray-code pattern projection in advance. In addition, the nonlinear response of the camera and color-transform functions between the projector and camera is also obtained through the method by Grossberg *et al.* [26]. The camera image was assumed to be similar to a user-perceived image and corrected the image to be projected to convert it to the desirable camera image as per  $F_{c2p}(I_c)$ .

### 2) INTENSITY MODIFICATION

Let the function for the intensity modification of the camera image be  $F_i$ . Then, two main cases can be considered: a case in which the whole area of the projection region is illuminated by a uniform gray light and another in which only the food region is illuminated. The first scenario was believed to be almost the same as when the brightness of the room light is changed in the general lighting condition and the second would be the user-perceived change in the appearance of the food surface. To consider these effects separately, two parameters were used:  $k_{if}$  for the brightness of the food region  $R_f$  and  $k_{ib}$  for the brightness of the background region  $R_b$ . Let each pixel in the camera image be  $p_b$ ; then, the relationship is given as:

$$I_i = F_i(I_c, k_{if}, k_{ib})$$

$$p_{xi} = \begin{cases} (k_{if}r_x, k_{if}g_x, k_{if}b_x) & \text{if } p_x \in R_f \\ (k_{ib}r_x, k_{ib}g_x, k_{ib}b_x) & \text{if } p_x \in R_b \end{cases} \quad (1)$$

$r_x, g_x, b_x$  represents red, green, and blue value in the image pixel  $x$ .

### 3) CHROMA MODIFICATION

The process of the chroma modification for the camera image is denoted as  $F_c$ . Each pixel value in the food region of  $I_c$  was transformed to the HSV color space and modified by applying  $k_{ch}$  to the saturation (chroma) value. If  $k_{ch} > 0$ , the chroma will be enhanced and vice versa:

$$I_{ch} = F_{c2p}(F_c(I_c, k_{ch}))$$

$$p'_{xch} = (h_x, (k_{ch} + 1)s_x, v_x) \text{ if } p_x \in R_f \quad (2)$$

### 4) HIGHLIGHT MODIFICATION

Additional highlight regions are provided through a simple observation-based method. Here, it was assumed that the

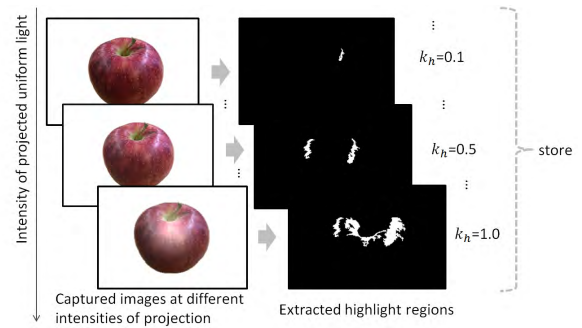


FIGURE 6. Highlight analysis.

user's direction of observation almost coincides with the camera direction. Fig. 6 illustrates the concept of the highlight analysis process from camera image  $I_c$ . First, each uniform grayscale image ( $r = g = b = const.$ ), in which the intensity is changed from 0 to 255, is individually projected onto the target object and observed through the camera. Here, the region in which the intensity in the captured image is saturated was considered the highlight region. Such regions were extracted from each captured image and stored as  $R_{kh}$ . As a very large highlight region may cause users to perceive unnaturalness, the upper limit size of highlighted regions was set as 20% of the entire food region in the camera image. It is assumed  $k_h = 1.0$  (MAX) when the highlighted area was the maximum (20% of the whole region) and  $k_h = 0.0$  (MIN) when there was no highlight. In practical implementation, the highlighted area recorded in advance is set to be the maximum intensity with respect to parameter  $k_h$ . Furthermore, when the intensity difference between a region and its surroundings is extremely large, a strong perceptual incompatibility occurs for users. Thus, intensities of the peripheral region of the highlight area are modified through Gaussian filtering (kernel size:  $9 \times 9$  pixels, and standard deviations: (2.0, 2.0)) so that the intensity is changed smoothly:

$$I_h = F_h(I_c, k_h)$$

$$p_{xh} = \begin{cases} (r_{x,max}, g_{x,max}, b_{x,max}) & \text{if } p_x \in R_{kh} \\ (Gaussian(r_x, g_x, b_x)) & \text{otherwise} \end{cases} \quad (3)$$

### 5) PARTIAL COLOR MODIFICATION

Although appropriate partial colors of each part of a food item will differ depending on the food type, one reasonable choice is to make the colors uniform in terms of the hue [20]. For instance, we can presume that in case of the apple, yellow or yellow-green regions showing the unripe nature should be changed to red, which occupies the majority of the area and signifies maturity. Specifically, first, for each continuous region on the image, the mode value of hue  $h_{mode}$  is calculated and pixels with other hue values are sorted in the descending order of their absolute difference with  $h_{mode}$ .  $k_h k_p \times 100\%$  of pixels with the larger hue differences are

replaced into  $h_{mode}$ .

$$\begin{aligned} I_{pc} &= F_{c2p}(F_{pc}(I_c, k_{pc})) \\ p'_{xpc} &= (h \bmod e, s_x, v_x) \text{ if } p_x \in R_{k_{pc}} \\ R_{k_{pc}} &= \text{Top 100 } k_{pc} \% \text{ pixel} \\ &\text{in descending order of } |h \bmod e - h_x| \end{aligned} \quad (4)$$

## V. EXPERIMENT

An experiment was conducted to evaluate the effects of the appearance of food, modified by the system, on the DAD.

### A. CONDITIONS

Three target objects were used: apple, steak, and sushi platter. The apple was considered to illustrate targets with a smooth surface, which will easily produce highlight and a remarkable hue. On the contrary, steak was adopted as an example of targets with fine irregularities on the surface, few highlights, and a low hue value. The sushi platter was adopted as a target example containing multiple objects with different colors. To maintain the uniformity in the appearance of targets during the experimental period, the only real object used was the apple; colored food samples made of vinyl chloride were used for the other target examples (products by maiduru pro, <http://www.maiduru.biz/>, Accessed on: 15 Jun. 2018). The experiment was performed by changing five parameters  $k_x$  for intensities (food and background area), chroma, highlight, and partial color of the objects. Each factor had three parameter values; therefore, the total number of conditions was 48 (three targets  $\times$  (five factors  $\times$  three conditions + one original)).

### B. PROCEDURE

First, the experimenter asked a participant to take a simple color-vision test. Next, he/she was asked to sit at a location from where the target could be observed. Among the three objects, one was chosen randomly and placed on the plate. An image with a randomly selected condition from among the 20 conditions was chosen and projected onto the target. Here, the evaluation of the subjective value of the DAD based on the appearance and by using the absolute value was very vague, and the interpretation of each value may differ for each participant. To alleviate this, a pairwise comparison approach was adopted, in which participants observed two conditions alternatively and evaluated the difference [27] in addition to performing evaluation according to the absolute value. First, the projection result of one condition was displayed, and then the second condition randomly chosen by the participant's key stroke was projected. He/she was allowed to repeat switching between the two conditions for comparison as many times as required, and was asked to provide relative evaluation on a 5-point scale, in which 1 indicates that the former condition is clearly better than the other, whereas 5 indicates the latter is clearly better. A scale of 3 indicated that both were comparable. Then, the participant also rated each condition on a 7-point-Likert rating scale

representing the absolute DAD. This procedure was repeated for  $20 \times 2$  randomly selected conditions. After a few minutes break, the procedure was repeated for the remaining two target foods. Finally, an interactive interview was conducted to obtain feedback on the experiments from the participants.

## C. RESULTS

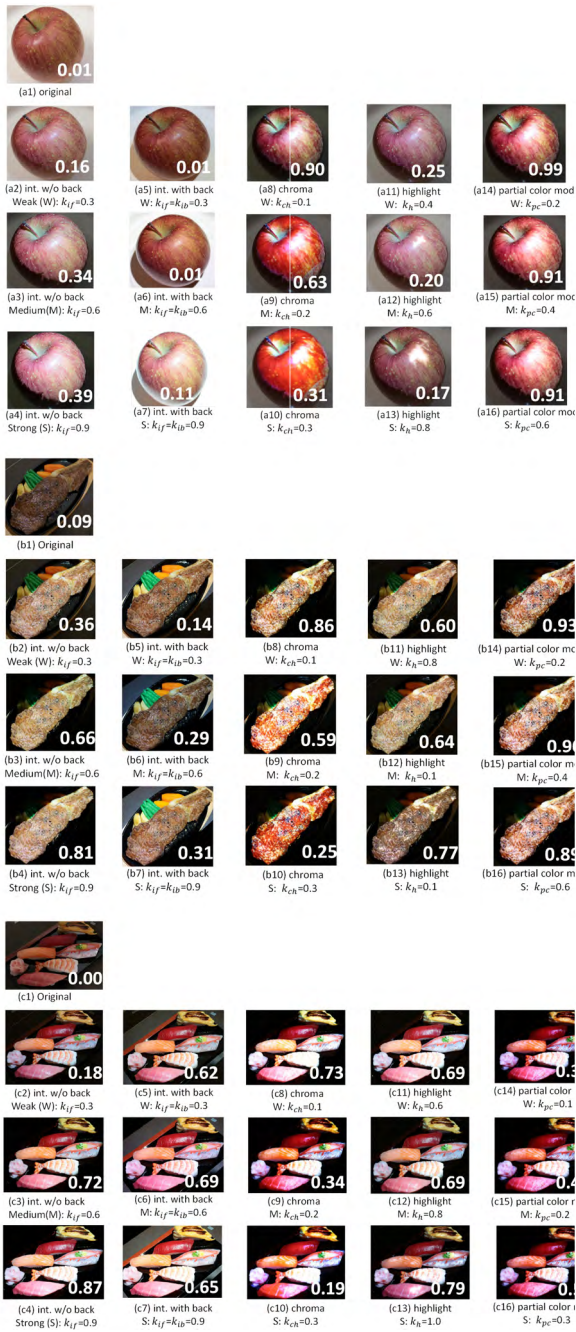
The participants included six Japanese male participants (aged: 22–25); they were university students with normal color vision. A total of 240 samples were used for each target (6 participants  $\times$  20 pairs  $\times$  2 conditions (120 pairs for each condition)). From these pairs, each DAD for the 16 conditions of each target, from 0.0 (worst) to 1.0 (best), was calculated using Koyama's method, in which  $y$  is calculated by optimizing equation (5) proposed in [26].  $Q$  includes each pair of condition for the same appearance factor with different strengths.

$$\begin{aligned} \min_y (E_{relative}(y) + \omega E_{continuous}(y)) \\ E_{relative}(y) &= \sum_{(i,j) \in P} \|y_i - y_j - d_{i,j}\|^2 \\ E_{continuous}(y) &= \sum_{(i,j) \in Q} y_i - \frac{1}{N_i} y_i^2 \end{aligned} \quad (5)$$

Each projection condition and the calculated DAD are shown in Fig. 7. The subjective values of each condition on the 7-point Likert rating scale are shown in Fig. 8. For these subjective values, the Kruskal–Wallis test was first used to analyze the difference among the conditions for each target and found significant differences (apple:  $p < 0.01$ , steak:  $p < 0.01$ , sushi:  $p < 0.01$ ). In addition, the Games–Howell test was conducted to detect the significant differences ( $p < 0.01$ ) among each pair of conditions and the original image. For the apple images, significant differences were observed in chroma [a8 weak (W)], highlight [a13 strong (S)], and partial color modification [a14 (W), a15 Middle (M), a16 (S)]. For the images of steak, significant differences were observed in the intensity change in the food region [b3 (M)], chroma [b8 (W), b9 (M)], highlight [b12 (M), b13 (S)], and partial color modification [b14 (W), b15 (M), b16 (S)]. For the images of sushi, intensity was observed to change in the food region [c3 (M)]. All statistical results are listed in Tables 1–3 in the appendix.

## D. DISCUSSION

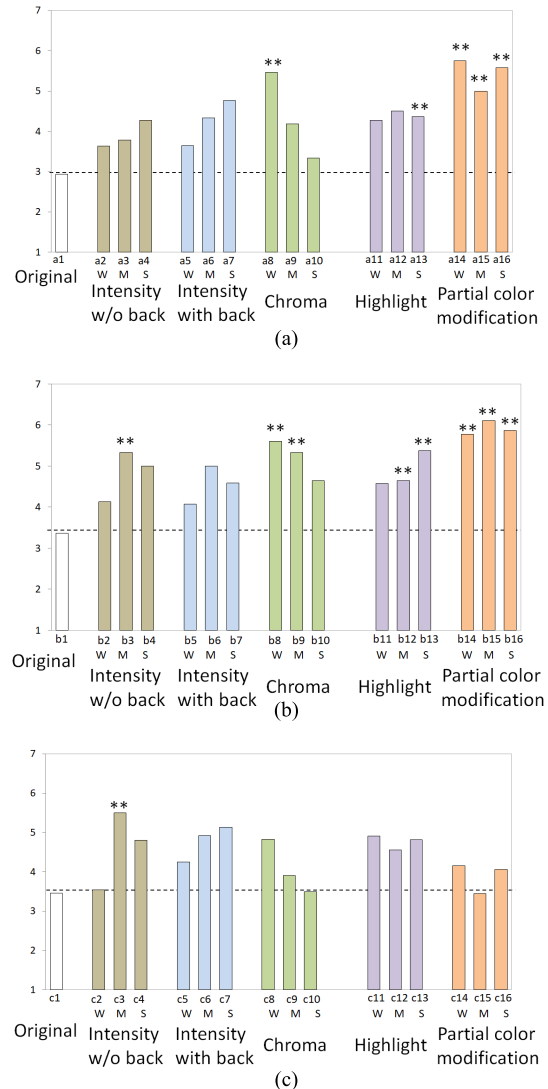
When the brightness was simply changed uniformly for the original image, no improvement was observed in the DAD of the three targets. Further, in the case where the chroma was slightly emphasized [x8 (W)], significant improvements were observed for apple and steak images. In contrast, in x9 (M) and x10 (S), which further emphasizes the chroma, the DAD decreased. In the interview conducted after the experiment, three participants said that the apple looked like an artifact, and one participant said that the image looked like a painting of an apple for x9 and x10. Accordingly, the author concludes



**FIGURE 7. Experimental projection conditions for three target foods. The values in each image are the DAD computed using (5).**

that a slight chroma enhancement improves the DAD of the food.

In addition, by emphasizing the highlights for apple and sushi, the DAD was improved. The images of steak showed most significant effects among all three target foods. According to the interviews, one participant stated that the highlight regions looked shiny resembling the application of oil or sauce, and thus appearing juicier. For the apple image, for which highlights had a small influence, one participant commented that “I found that observing highlights is nothing



**FIGURE 8. Absolute DAD for each condition in the evaluation. \*\* indicates significant difference ( $p < 0.01$ ) from the original appearance.**

more than a physical phenomenon in a real environment and does not affect the perceived deliciousness, unlike when viewing an apple in photos.”

Furthermore, for the apple and steak cases, partial color modification also had a significant effect. These targets are common in terms of the existence of dominant colors over the entire region; this suggests that the DAD can be possibly improved for such target foods by making them appear uniform. In the sushi platter, each type of sushi showed different representative colors; however, the current system created uniformity by using the representative hue value calculated from the entire region. Thus, this was inferred to be one of the plausible explanations for the sushi platter not being affected by this factor. The simple solution is to segment each food component (e.g., by the method proposed in [28]) and to apply different parameters to the regions of each component.



TABLE 1. Apple.

APPLE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.39	0.69	0.73	0.93	0.27	0.04	0.00	0.43	0.95	0.63	0.03	0.00	0.00	0.00	0.00
2		1.00	1.00	1.00	0.98	0.60	0.00	0.99	1.00	1.00	0.64	0.21	0.00	0.00	0.00	0.00
3			1.00	1.00	1.00	0.98	0.07	1.00	1.00	1.00	1.00	1.00	0.05	0.32	0.02	0.00
4				1.00	1.00	1.00	0.60	1.00	1.00	1.00	1.00	1.00	0.43	0.93	0.36	0.00
5					1.00	0.96	0.57	0.00	0.97	1.00	1.00	0.66	0.46	0.00	0.01	0.00
6						1.00	0.47	1.00	0.99	1.00	1.00	1.00	0.32	0.92	0.21	0.00
7							1.00	0.88	1.00	0.79	0.99	1.00	1.00	0.70	1.00	0.58
8								1.00	0.68	0.01	0.12	0.21	0.02	1.00	0.99	1.00
9									1.00	0.99	1.00	1.00	1.00	0.51	0.97	0.42
10										1.00	0.90	0.86	0.01	0.07	0.00	0.00
11											1.00	1.00	0.08	0.47	0.04	0.00
12												1.00	0.17	0.77	0.06	0.00
13													1.00	0.05	0.25	0.00
14														1.00	0.91	1.00
15															1.00	0.81
16																1.00

TABLE 2. Steak.

STEAK

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.10	0.00	0.02	0.20	0.03	0.34	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00
2		1.00	0.03	0.66	1.00	0.67	1.00	0.07	0.03	0.99	1.00	0.78	0.02	0.02	0.05	0.00
3			1.00	0.03	1.00	0.87	1.00	1.00	0.72	0.57	0.67	1.00	1.00	0.98	0.98	0.00
4				1.00	0.64	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.98	0.95	0.96	0.00
5					1.00	0.65	1.00	0.07	0.03	0.99	0.99	0.76	0.02	0.01	0.04	0.00
6						1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.87	0.84	0.00
7							1.00	0.75	0.81	1.00	1.00	1.00	0.87	0.45	0.41	0.31
8								1.00	0.59	0.48	0.58	1.00	1.00	1.00	1.00	1.00
9									1.00	0.63	0.49	0.59	1.00	1.00	1.00	1.00
10										1.00	1.00	0.69	0.25	0.28	0.09	0.00
11											1.00	0.53	0.18	0.22	0.05	0.00
12												1.00	0.61	0.22	0.29	0.05
13													1.00	0.99	0.96	0.96
14														1.00	1.00	1.00
15															1.00	1.00
16																1.00

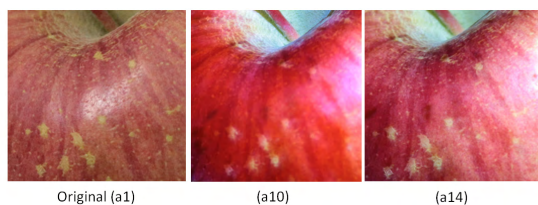


FIGURE 9. Comparison by enlarged a1 (original), a10 (strong chroma, saturated), and partial color modification.

As an example of the case of apple in Fig. 9, a10 (saturated chroma) is almost the same as the condition under a uniform strong red light and is similar to existing studies [17]–[19]. Meanwhile, one of the representative conditions of the proposed method is a14 which determined light values in a pixel-wise manner. Compared with a10 and the original (a1), we can see that the original texture of the apple was partially

TABLE 3. Sushi.

SUSHI

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	1.00	0.00	0.40	0.83	0.11	0.11	0.14	0.98	1.00	0.17	0.46	0.03	0.99	1.00	0.84
2		1.00	0.00	0.63	0.99	0.16	0.18	0.18	1.00	1.00	0.26	0.66	0.01	1.00	1.00	0.98
3			1.00	0.83	0.00	0.97	0.99	0.82	0.20	0.02	0.94	0.03	0.92	0.26	0.11	0.27
4				1.00	0.98	1.00	1.00	1.00	1.00	0.57	1.00	1.00	1.00	1.00	0.95	1.00
5					1.00	0.70	0.69	0.79	1.00	0.94	0.82	1.00	0.98	1.00	0.94	1.00
6						1.00	1.00	0.95	0.24	1.00	0.98	1.00	0.94	0.73	0.99	0.99
7							1.00	0.93	0.23	1.00	0.97	1.00	0.93	0.71	0.99	0.99
8								1.00	0.98	0.29	1.00	1.00	1.00	0.97	0.81	1.00
9									1.00	0.99	0.98	1.00	0.82	1.00	1.00	1.00
10										1.00	0.31	0.68	0.12	1.00	1.00	0.93
11											1.00	0.99	1.00	0.97	0.81	1.00
12												1.00	0.79	1.00	0.99	1.00
13													1.00	0.83	0.52	0.95
14														1.00	1.00	1.00
15															1.00	1.00
16																1.00

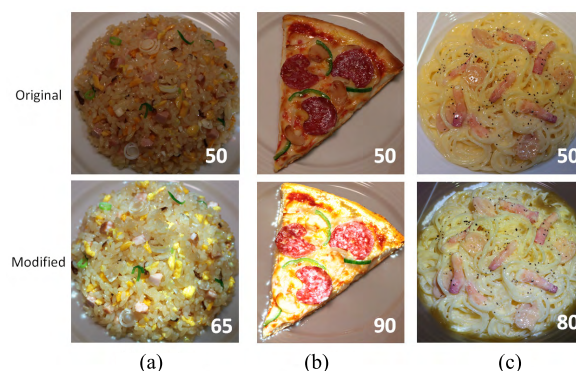


FIGURE 10. Original and modified appearances for three food items. (a) Fried rice. (b) Pizza. (c) Pasta.

lost by the uniform strong red light. On the other hand, a14 preserves the original texture and naturally changes the color as well. From these scenarios, it is clear that one of the advantages of the proposed method is the capability of changing locally according to each part; thus, it can be expected to lead to a significant improvement in DAD.

All targets showed significant differences in the DAD under some conditions compared with their original appearance, as discussed earlier. Thus, the appearance of food can be improved with respect to deliciousness by using our system in an appropriate manner.

## VI. SIMPLE SYSTEM APPLICATION AND ITS EVALUATION

A simple application of the proposed system was developed to control the DAD through each feature parameter by using a slider GUI. If a new parameter is set by the user, the system projects a new image in accordance to the parameters onto the target food.

An additional informal experiment was conducted to confirm the feasibility of the application. One participant (male, with normal color vision; hereinafter, participant A) was asked to control each parameter so that the target food

appeared the best in terms of the DAD. He was allowed to repeat the parameter settings until he was satisfied. After parameter setting, another participant (female, with normal color vision; hereinafter, participant B) was asked to observe the target object, both with the projection image set by participant A and with only environmental lighting (i.e., the original appearance). Participant B was allowed to repeat switching between the two conditions for comparison as many times as required and was asked to score the DAD for the modified appearance from 0 to 100, considering the score of the original appearance was 50. These procedures were repeated for three target foods.

Fig. 10 illustrates the original and modified appearances for three food items with scores by participant B. Each of the modified appearances achieved a higher score than the original image. Although these results cannot be generalized, the proposed application was at least confirmed to work as expected for some cases.

The average duration for parameter setting for each target was 22 s. As discussed in the next section, this process should be automated for practical use.

## VII. CONCLUSION AND FUTURE WORK

This paper proposed a methodology and a projector-camera system that analyzes the appearance of target foods in a simple manner and changes it to increase the subjective deliciousness of the food item in a real environment. Through user study, it was confirmed that it is possible to enhance the deliciousness of food based on its appearance compared to when it is under normal lighting by projecting an appropriate image onto the target food item.

However, only three foods were used as targets for the system-based evaluation; therefore, the results cannot be generalized. Furthermore, actual meals include different food items with various appearance characteristics. Therefore, a uniform process for each of these would be required; generalization of the projection target is a major issue to be addressed in the future. Here, the author hypothesizes that if the food is divided into classes in accordance with food category, and appearance such as color, and texture, parameters suitable for each class would be consistent. A analysis of the relationship between foods in various categories and appearance factors to achieve appropriate classification is the next step.

While the user was assumed to adjust each parameter of the appearance factor, auto-optimization of each parameter based on the above hypothesis is also an interesting approach for future work. In this case, one feasible way is to estimate the category of the food from the input image and optimize the parameters according to the DAD model of that food category prepared in advance.

In addition, the evaluation of changes of multiple factors is also a challenge. The method using crowdsourcing [27] is also useful to determine the function of the relationship between multiple parameters as input and the DAD as output. However, as our research is targeted toward the change in

appearance of target foods and user's observation in a real environment instead of food images, we could experience a crucial problem in the modification of the original appearance owing to imaging. Furthermore, in the real environment, we should consider the differences of the optical properties between surfaces of a real food item and a food sample employed in this study.

Finally, the proposed system cannot yet be used to perform real-time processing. It will be desirable to project an appropriate image onto a projection target that changes sequentially during eating. While full real-time geometric and photometric calibrations between pro-cams would be difficult, an imperceptible method such as that in [29] may be used as a part of future work if one update per several seconds is considered to be sufficient for the calibration.

## APPENDIX

### A. STATISTICAL RESULTS

Results ( $p$ -values) of Games–Howell test for all pairs in Section V are as follows.

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