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Edible Retroreflector Made of Candy

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ABSTRACT Recently, methods of projecting images onto food using a projector have been the subject of various studies because they have the potential to intervene in the visual appreciation of food, and also because such technology has the potential to create new production methods and services related to food. Since projection can be achieved easily using an optical marker, an edible retroreflector made of agar has been proposed; however, an agar retroreflector had the drawback of a short lifetime. In this paper, we propose an edible retroreflector made of candy, which is resistant to drying and can be used for a long time. Two types of retroreflectors, one with single layer and the other with two layers, were proposed and fabricated. The evaluation experiments showed that the proposed retroreflectors had sufficient reflection coefficient R of up to 84.76 for the single-layered prototype and up to 173.05 for the two-layered prototype. These coefficients are comparable to the coefficient 70 of commercially available glass-bead-type retroreflectors, which are strong enough to be used as markers for a camera. The prototype was also able to maintain its functionality for 10 days from the fixed-point observation. Furthermore, dynamic projection mapping on a pancake and motion capture were successfully demonstrated to show the potential applications.

INDEX TERMS Candy, edible, food, optical marker and retroreflector.

I. INTRODUCTION

In recent years, projection mapping, a technology that uses a projector to project images onto the surface of a three-dimensional object, has been attracting attention. Traditionally, static walls and other objects have been used for projection.

In the field of VR/AR, food has been attracting attention in recent years. In particular, methods of projecting images onto food using a projector have been the subject of various studies because they have the potential to intervene in the visual appreciation of food, and to manipulate and present stimuli to various senses, such as taste, appetite, and texture [1]–[5]. Also, there have been attempts to apply projection mapping onto food and cuisine as services [6].

In order to perform geometrically consistent projection mapping on a projection object such as a dish or food, it is necessary to know the position and posture of the object. Visual measurement methods are commonly used to measure the position and posture of an object, but it is generally difficult to recognize the object and estimate its posture using images. In particular, in the case where the projection

object is food, food includes many handmade items, and the objects do not always have exactly the same shape, which makes position and posture estimation difficult. Although recent machine learning-based methods can overcome this difficulty to some extent, it is necessary to learn many images of the object to be recognized. In addition, projection mapping onto food is intended to be used in cafes and restaurants, where menus are updated frequently, and thus the appearance and shape of the objects are expected to be changed frequently. Considering the high frequency of menu updates, from a cost perspective it is expected to be difficult to update the recognition algorithm every time the menu is updated.

To overcome this difficulty, our group has proposed an edible retroreflector made of agar [7], [8]. This optical device works as an optical fiducial marker that can facilitate visual position and posture estimation. A retroreflective material is an optical element that reflects light straight back toward the light source. When a light source is placed near the camera, the retroreflective material appears very bright in the camera image, and can be stably detected by image processing. Because of this property, they are also used as markers for motion capture. However, conventional retroreflective materials are made of plastic or glass and are inedible, so they are not suitable for use on food because of hygiene concerns

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and the risk of accidental ingestion. To solve this problem, the proposed device was made only from foods.

The previous edible retroreflector had the drawback of a short lifetime due to evaporation of water contained in the device. Previous edible retroreflective materials consist of agar, granulated sugar and water, and since water occupies most of their volume, they dry out and change shape in a short time. It has been empirically known that the function of the reflective material lasts for about an hour in a relatively humid environment, but it loses its function in less than 10 minutes in a dry, heated environment in winter [7].

In this paper, we propose an edible retroreflector made of candy, which is resistant to drying and can be used for a long time. We also report the results of evaluating the reflective properties of the prototype retroreflective material to validate the proposed device. Our main contributions are as follows:

- 1) **Reduced isomaltulose as suitable material:** Reduced isomaltulose was found to be suitable for molding optical elements because it was less likely to crystallize and caramelize. It is desirable that crystallization and caramelization do not occur easily, because they result in the loss of transparency.
- 2) **Easy-to-implement fabrication method of candy retroreflector:** We developed a fabrication method using off-the-shelf retroreflector, silicone resin and a microwave oven.
- 3) **Two-layered structure for stable performance:** We developed a structure for an edible retroreflector made of two layers of candy, combining two candy retroreflector. This structure was confirmed to have (i) stable performance even with moist food, (ii) stronger reflection due to the structure, and (iii) no need to distinguish between front and back, and improvement of convenience.
- 4) **Demonstrations of potential applications:** Dynamic projection mapping on a pancake and motion capture were successfully demonstrated to show the potential applications of the proposed device.

II. RELATED STUDIES

There have been widespread attempts to accentuate and improve the eating experience by adding images to food. Meta-cookies [9] and augmented satiety [10] are examples of direct methods of presenting information to a human using a head-mounted display. These techniques modulate the taste and satiety by modifying the appearance of the food that the person is about to eat, such as its texture and size. There have also been reports of attempts to change the appearance of food in order to present the sensation of eating something different from what someone is actually eating [11]. These attempts require information on the location of the target food, which is conventionally detected using image processing by creating the right environment for image detection.

As for attempts to project images onto tables and dishes, for example, Mori *et al.* proposed Dining Presenter [1], which projects images onto tables, and Kita *et al.* proposed

Spot-Light [2], which projects images and sound fields onto dishes. In Spot-Light, based on the images of food measured by a camera, it is proposed to project and superimpose images on the actual food, adjusting the color saturation and other parameters to make the food taste better.

As a more direct attempt to modulate the sensation of taste and deliciousness based on projection, Nishizawa *et al.* have investigated the effect of color projection on taste [3], and Fujimoto has reported a projection-based food appearance optimizer [4]. The effect of projecting images onto a dining table on the perception of food has also been reported [5].

From the viewpoint of optics, a method of fabricating optical devices from food has been discussed, in which lenses are formed from candy; this approach has been applied to optical education [12], [13]. As new possibilities for optical devices, a method of fabricating lasers from edible materials [14] and a method of fabricating holograms using silk molecules [15] have been reported.

In addition, in a previous study before the present research [7], an edible retroreflector made of agar was proposed. By forming transparent foodstuff into a corner-cube prism array shape, the agar edible retroreflector achieves retroreflection; agar was selected for use as the retroreflective material after comparing various jelly-like foodstuffs. An optical fibre made of agar was also reported [16].

As prior examples of making markers from food so that the markers themselves can be eaten, there have been reports of attempts to create QR codes from various food materials, such as printing QR codes on rice paper with water-based ink [17], adding edible QR codes to cookies [18], and adding QR codes to waffles with chocolate [19]. The application of an edible QR Code in the medical field has also been discussed [20]. In these examples of a QR Code made from food, the visibility of the code changes depending on the lighting conditions, which makes the code unstable when it is photographed by a camera to detect the position and posture of the object. In contrast, the creation of AR markers by adding chocolate patterns to conventional agar retroreflective material has been reported [7]. In this example, the agar retroreflective material used as a marker itself has retroreflective reflectivity, which allows us to capture the strong reflection of light in the image, thus enabling stable detection of the position and orientation of the object regardless of the lighting conditions.

III. PROPOSED METHOD

Here, the proposed method of forming a retroreflector from candy is described.

A. PRINCIPLE OF RETROREFLECTION

There are two main types of retroreflector structures: the glass bead type and the corner cube type. In order to fabricate a glass bead reflector, it is necessary for the material to have a high refractive index of about 2.0; however, the refractive index of candy is as low as 1.52. Therefore, in this study, we fabricated retroreflectors with a corner cube-type structure. As shown in Fig. 1, the corner cube-type retroreflectors consist of three precise planes that are combined at right

angles to each other to form a vertex, and the structure reflects light back in the direction of the light source by total reflection at each plane. In order to achieve this structure with candy, we used a commercially available corner cube-type retroreflector mold made of food-grade silicone resin, and poured candy into the mold. A photograph of the fabricated silicone resin mold is shown in Fig. 2.

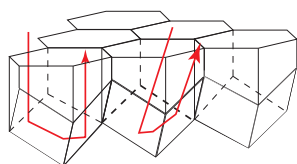


FIGURE 1. Principle of the corner cube-type retroreflector.

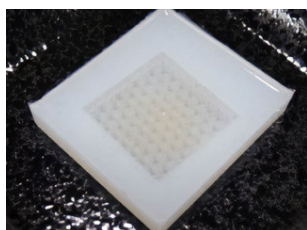


FIGURE 2. Photograph of a silicone resin mold.

B. FABRICATION PROCEDURE

The fabrication procedure of the candy retroreflectors is shown in Fig. 3, and a photograph of the fabricated retroreflector prototype is shown in Fig. 4. Since candy is sensitive to moisture, the following procedure was carried out in an environment where the temperature and humidity were kept to be 18-24°C and below 50%, respectively.

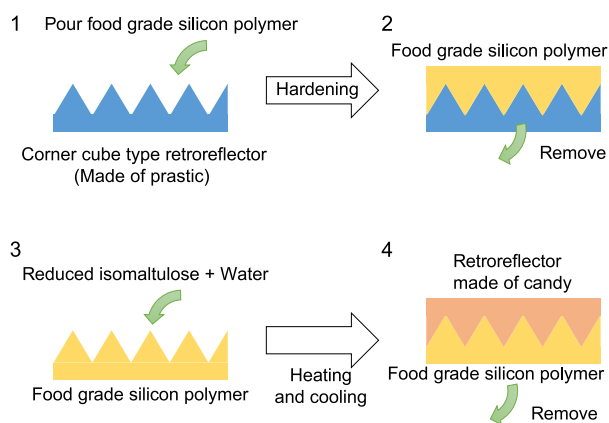


FIGURE 3. Schematic diagram of the proposed fabrication process.

Usually, to make a candy of a specific shape, a method called *nagashi-ame* in Japanese or *sucre coul e* in French is used, in which melted candy is poured into a mold. However, because the shape of the corner cube was complicated, the candy could not be formed by using *nagashi-ame* because the candy did not fill the entire mold. Thus, in the proposed

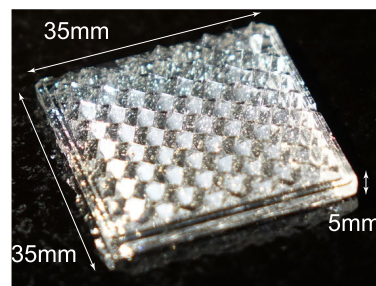


FIGURE 4. Photograph of the prototype.

method, sugar and water were placed on the mold, and the mold was then heated so that the sugar could be melted in the mold.

- 1) Place a commercial corner cube-type retroreflector (Edmund Optics, each cube size 3 mm) in a flat-bottomed plastic container so that the corner cubes face upward. Then, pour food-grade silicone resin (Engraving Japan HTV-4000) on top until the corner cube-type retroreflector is covered. The dimensions of the commercial retroreflector were 35 × 35 × 5mm, and the dimensions of the container were 60 × 60 × 18mm.
- 2) Leave the silicon resin at room temperature for about 6 hours to harden, and remove the commercial corner cube.
- 3) Place 5g of sugar and 1.5g of water on the silicon resin mold, and heat the mold in a microwave oven until the water evaporates but the candy does not caramelize. In this paper, the candy was heated five times for 20 seconds in a microwave oven with a rated output of 550 W. The heating was divided into five steps in order to check the degree of caramelization of the candy and the boiling of the bubbles. In this process, the bubbles were initially bumpy, but gradually subsided. Further heating resulted in a highly viscous foaming state, and heating was terminated when this state was reached. Although it was difficult to measure the temperature of a solution in a microwave oven directly, the temperature of the solution in a pan was measured to be about 170°C when it was in the high viscosity foaming state. Thus, the temperature of the solution at which high viscosity foaming occurs was estimated to be about 170°C.
- 4) Scrape out the air bubbles from the bottom of the candy with a toothpick to remove them.
- 5) Place the candy on a marble stand and let it cool evenly at room temperature. Note that rapid cooling may cause the candy to crack. When the candy has solidified, remove it from the silicon resin mold. This completes the candy retroreflector.

C. TWO LAYERS OF CANDY RETROREFLECTIVE MATERIAL

The retroreflector used in this study had one flat side, and the other side contained an array of corner cubes. When used as a retroreflector, the flat side needs to face the direction

of incoming light. Thus, when placed on top of an object, the surface containing the array of corner cubes, which is important for retroreflection, touches the object. The candy retroreflector dissolves and changes its shape when it directly touches a moist object due to the high hydrophilic nature of the candy material. For example, if the candy retroreflector is to be used on moist food, the corner cube will dissolve, thus deforming and losing their function in a short time. Therefore, we also propose a structure for an edible retroreflector made of two layers of candy, combining two candy retroreflectors, as shown in Fig. 5. A very thin layer of air is formed between the two layers, so that light incident on the upper or lower layer undergoes total reflection at the corner cube surface on the opposite side of the layer.

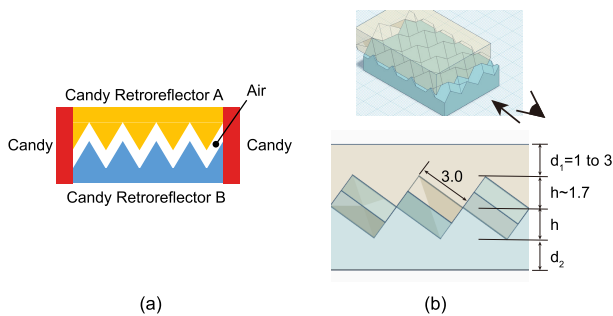


FIGURE 5. Schematic diagram of the two-layered structure (a) and the actual structure with dimensions (b). The thickness of the base layer of each retroreflector d_1 , d_2 varied from 1 to 3 mm, depending on the prototype. A thin layer of air was naturally formed between the layers due to manufacturing errors.

This structure prevents the corner cube surface from directly touching moist food, and stable performance can be expected even when the candy retroreflector is in contact with moist food. In addition, the second layer reflects the light that would have been transmitted through the first layer of the candy retroreflector, thereby improving the reflectivity. Furthermore, since both the top and bottom surfaces can function as a retroreflector, there is no need to distinguish between the front and back surfaces, which improves convenience.

D. PROCEDURE FOR FABRICATING A TWO-LAYERED CANDY RETROREFLECTOR

The fabrication procedure of the two-layered candy retroreflector is described below. Also, the fabricated two-layered candy retroreflector is shown in Fig. 6.

- 1) Place the two pieces of candy retroreflector together, as shown in Fig. 5. A thin layer of air was naturally formed between them by lightly overlapping them.
- 2) Weld the four edges with a trowel.
- 3) Allow the material to cool evenly and solidify to completion.

E. SELECTION OF SUGAR

The main ingredient used to make the retroreflector was sugar. Since a retroreflector has a structure in which incident

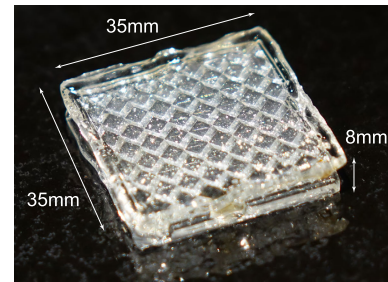


FIGURE 6. Photograph of the prototype with two-layered structure.

light passes through the inside of the element, it is desirable to use a material with high transparency and low light attenuation. However, caramelization, a brownish coloration, may occur when the sugar is boiled to a high temperature, or crystallization may occur during subsequent cooling, causing the surface of the candy to become complex and uneven, and the surface to become cloudy, resulting in a loss of transparency. In order to select materials capable of producing more transparent candies, we investigated the degree of caramelization and crystallization of three types of sugar: granulated sugar, caster sugar, and reduced isomaltulose. Reduced isomaltulose is a kind of sugar made by reducing isomaltulose, which is contained in honey, etc. It is available as a disaccharide low-calorie sweetener.

Following the procedure shown in III-B, retroreflectors were fabricated five times using each sugar, and the degree of retroreflection and color saturation of the fabricated materials were evaluated from the retroreflection image of the prototype. The silicone resin mold and the photographic equipment were all the same, and the camera used in the measurement was one without gamma correction. Also, since the aperture of the camera was not changed throughout the measurement, the values of the measurement results could be compared for each sugar.

Retroreflection images of the prototypes were captured under coaxial illumination. This means that the light source and the camera were installed optically on the same axis via a half mirror. From the captured image, the average pixel value was measured as the degree of retroreflection, and the average saturation in HSV color space was measured as the degree of caramelization, since its value increases when the object is colored. A projector (EPSON 4950WU) was used as the light source, and a camera (Photron IDP-ExpressR200) with a lens (Fujinon TVILens HF25HA-1B) was used to capture the retroreflection image.

The results are shown in Fig. 7. These results indicate that the degree of retroreflection of the prototype made of reduced isomaltulose was highest. In fact, reduced isomaltulose was less likely to crystallize than the other sugars. Also, the color saturation was lowest in the case of reduced isomaltulose, indicating that it did not readily caramelize. Therefore, in this study, we used reduced isomaltulose to fabricate the candy retroreflector.

	Granulated sugar	Caster sugar	Reduced isomaltulose
Average of the degree of retroreflection (variance)	74.9 (2069.11)	73.28 (825.01)	133.01 (75.18)
Average of saturation (variance)	97.59 (7415.61)	105.77 (5916.7)	14.38 (36.7)

FIGURE 7. Evaluation results of the degree of retroreflection and the average saturation.

IV. PERFORMANCE EVALUATION

A. REFRACTIVE INDEX MEASUREMENT

The refractive index of the reduced isomaltulose candy was measured using a refractometer (Kyoto Electronics Industry RA-600). Since the refractometer required that the object be adhered to the glass surface, the refractive index of melted reduced isomaltulose candy before solidifying was measured to be 1.5266. The refractive index increases when the density increases, and the density of material is inversely proportional to the temperature in almost all cases [21]. Since the temperature is lower in the solid state, the refractive index in the solid state is expected to be slightly higher than the measured value.

B. TRANSMITTANCE MEASUREMENT

The transmittance T of the reduced isomaltulose candy was measured using a spectrophotometer (U-3000, Hitachi, Ltd.). Air was used as a reference. The result is shown in Fig. 8. The result shows that the material has high transmittance in the visible to near-infrared region.

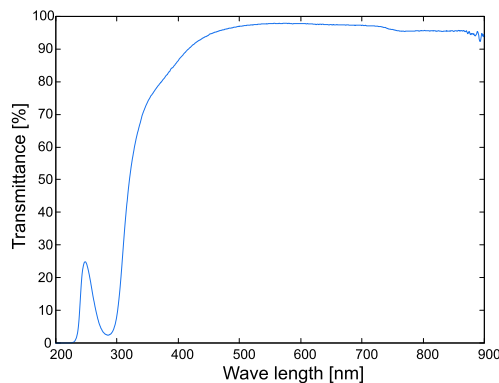


FIGURE 8. Transmittance of the candy made of reduced isomaltulose.

C. MEASUREMENT OF RETROREFLECTIVE PERFORMANCE

In order to investigate the retroreflective performance of each of the prototype single- and two-layered candy retroreflectors, we conducted measurements in accordance with Japanese Industrial Standards (JIS) Z 9117:2011 (Retroreflective materials). However, the test was conducted with a test object area of only 3.5 cm × 3.5 cm, which is smaller than that specified in the JIS standard.

The test method according to the JIS standard is as follows. First, the angle between the incident light and the normal of the retroreflector is called the angle of incidence, as shown in the Fig. 9. The angle between the incident light and the direction to an observer is called the angle of observation. The retroreflection coefficient is measured twice, once when the retroreflective material is not rotated and once when it is rotated 90 degrees around its normal. This angle is called the angle of rotation. The retroreflection coefficient R is defined as:

$$R = E_r \frac{15^2}{E_s A}$$

where E_r is the illuminance measured by placing the illuminance meter in the retroreflector position directly opposite the light source, A is the surface area of the retroreflector, E_s is the illuminance on the illuminance meter in the measurement configuration, and 15 m is the distance between the center of the retroreflector and the illuminance meter. The angles of observation were 0.2°, 0.33° and 2.0°, the angles of incidence were 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45°, and the angles of rotation were 0° and 90°. The values of the angles of observation and angles of rotation were in accordance with JIS standards. The angle of incidence is specified in the JIS standard to be measured at 5°, 30°, and 40°, but we measured more angles of incidence for reference. The test was conducted at the Nissenken Quality Evaluation Center because we did not have an environment where the necessary 15 m distance could be secured.

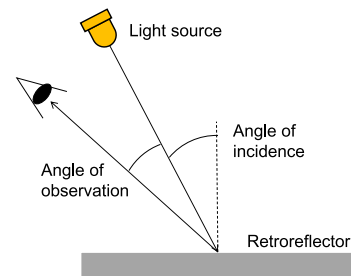


FIGURE 9. Schematic diagram of the measurement setup for the JIS standard.

The retroreflection coefficients R of the single-layered candy retroreflector with the angle of rotation of 0° are shown in Fig. 10.

The results show that the retroreflection coefficient decreases as the angle of incidence increases in the entire range of 0° to 45° for both 0° and 90° angles of rotation, indicating that the prototype worked as a retroreflector.

At an angle of incidence of 5° and an angle of observation of 0.2°, the retroreflection coefficient R for the prototype candy retroreflector was 84.76 at a 0° angle of rotation and 82.6 at a 90° angle of rotation, whereas the standard retroreflection coefficient R for commercially available retroreflectors is 325 for the corner-cube-type, 70 for the glass-bead-type for long-term outdoor use, and 35 for the

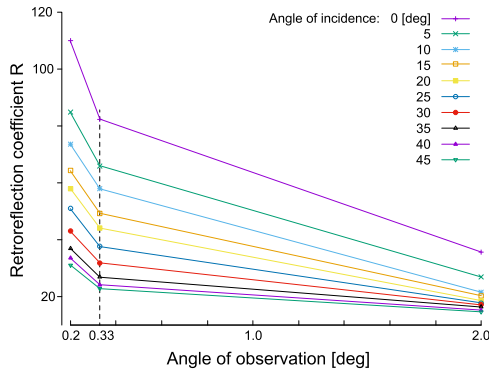


FIGURE 10. Retroreflection coefficient R of the single-layered prototype for a 0° angle of rotation.

glass-bead-type for indoor use or short-term outdoor use. Therefore, the reflective performance of the prototype candy retroreflector was not as good as that of the commercially available corner-cube-type retroreflector, but it was better than that of the commercially available glass-bead-type retroreflector.

The retroreflection coefficients *R* of the two-layered candy retroreflector obtained from the test results are shown in Fig. 11 for a 0° angle of rotation. Very similar results were obtained for a 90° angle of rotation.

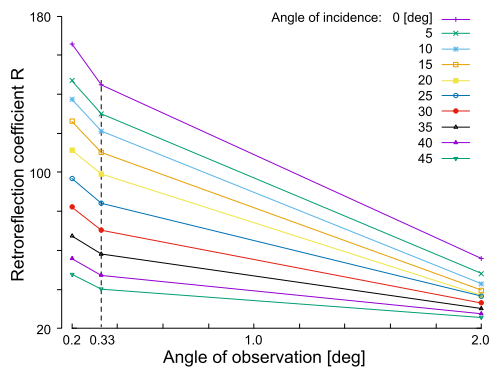


FIGURE 11. Retroreflection coefficient R of the two-layered prototype for a 0° angle of rotation.

The results show that the retroreflection coefficients decrease as the angle of incidence increases in the entire range from 0° to 45° for both 0° and 90° angles of rotation, indicating that the prototype candy retroreflector is retroreflective.

At an angle of incidence of 5° and an angle of observation of 0.2°, the retroreflection coefficient *R* for the prototype two-layered candy retroreflector was 165.86 at a 0° angle of rotation and 173.05 at a 90° angle of rotation, which were higher than those of the single-layered candy retroreflector.

D. IMAGE MEASUREMENT EXPERIMENT UNDER COAXIAL ILLUMINATION

In order to investigate whether the fabricated single- and two-layered candy retroreflectors can be used as camera markers, we used the same system used for evaluating sugars,

in which a light source, a camera, and a lens were optically coaxial via a half mirror. The angles of incident light to the candy retroreflector were around 0 degrees. The results are shown in Fig. 12. In both Figures 12 (a) and (b), the left-most object is the single-layered candy retroreflector, and the second object is the two-layered candy retroreflector. For comparison, a glass-bead-type retroreflector is shown in the third image from the left, and a plastic corner-cube-type retroreflector is shown in the fourth image.

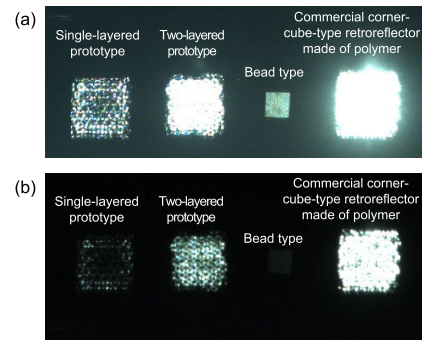


FIGURE 12. Photographs of the epi-illuminated prototypes and commercial products. The top photograph was taken with a large aperture (a), and the bottom photograph with a smaller aperture (b).

For Fig. 12 (a), the average of the pixel values in the entire retroreflector area was calculated for each retroreflector. The results were 122.9 for the two-layered candy retroreflector, 23.2 for the single-layered candy retroreflector, 19.6 for the glass-bead-type retroreflector, and 220.6 for the plastic corner-cube-type retroreflector.

The glass-bead-type retroreflector that resulted in the weakest reflection was also a commercially available retroreflector. Therefore, both the single-layered and two-layered candy retroreflectors, which were found to have a stronger reflection strength than the bead-type retroreflector, can be used as camera markers. On the other hand, it has been reported that the retroreflector made of agar had the same reflection strength as that of the glass-bead-type retroreflector when photographed using the same experimental method as in this experiment [7], suggesting that the candy retroreflector has a stronger reflection strength than the agar retroreflector.

It was also found that the two-layered candy retroreflector had a stronger reflection strength than the single-layered candy retroreflector, although it was not as strong as the plastic corner-cube-type retroreflector. This indicates that the two-layered candy retroreflector is easier to detect as a marker for cameras than the single-layered candy retroreflector.

Fig. 13 shows the results of image measurement under coaxial illumination when the surface of the two-layered candy retroreflector was changed.

The averages of the pixel values in the entire retroreflector area was calculated for Fig. 13 (a) and (b), respectively. The results were 135.458 for (a) and 153.844 for (b). From the results, it can be said that the two-layered candy retroreflector has sufficient reflective performance as a camera marker on

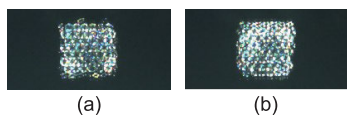


FIGURE 13. Photographs of the coaxially illuminated two-layered prototype, showing the front side (a) and back side (b).

both sides, regardless of whether the front or back surface is used. The reason for the difference in the average pixel values between (a) and (b) may be due to individual differences in the performance of the combined candy retroreflectors themselves.

E. CHANGE IN THE REFLECTION STRENGTH OVER TIME

Using the same system as described in the previous section, we conducted fixed-point observations of the degree of retroreflection as a whole over time. The experiment was conducted using a single-layered candy retroreflector and an agar retroreflector for comparison. The observation was conducted during winter in Japan. The rooms where the observations were made were heated except for the third and fourth days and all nights. The environment in which the prototypes were stored was about 9°C when unheated and up to 20°C when heated, and the humidity ranged from 20 to 40%.

The results are shown in Fig. 14. The horizontal axis is the elapsed time, and the vertical axis is the average pixel value of the entire retroreflector area. The results show that the degree of retroreflection of the agar retroreflector significantly decreased after 60 minutes, whereas the candy retroreflector had sufficient intensity to be used as a marker for image measurement even after 10 days. Therefore, the candy retroreflector can be used for a long time even in a dry place such as a heated room in winter.

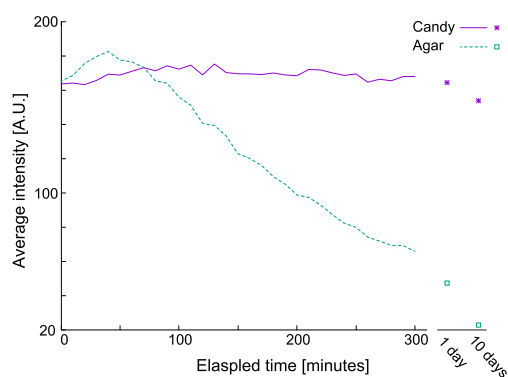


FIGURE 14. Average intensity profiles of the light reflected by the retroreflectors made of candy (a) and agar (b).

F. RETROREFLECTION MEASUREMENT WHILE IN CONTACT WITH MOIST FOOD

Using the same system, we conducted fixed-point observations to see how much the degree of retroreflection of the two-layered candy retroreflector changed with time when it was in contact with moist food. The experiment

was conducted on a two-layered candy retroreflector and a single-layered candy retroreflector for comparison, and ice cream was used as an example of moist food. The dimensions of the samples were 34 mm (length), 34 mm (width), and 7 mm (thickness) for the two-layered candy retroreflector, and 34 mm (length), 34 mm (width), and 5 mm (thickness) for the single-layered candy retroreflector. The experimental setup is shown in Fig. 15.



FIGURE 15. Photograph of the prototypes on ice cream to observe the change in reflection intensity over time.

The images measured at 0, 30, and 60 minutes after the start of the experiment and the experimental results are shown in Fig. 16. The horizontal axis is the elapsed time and the vertical axis is the average pixel value of the entire reflective material. The results show that the single-layered candy retroreflector did not have sufficient reflection strength to function as a camera marker at 0 minutes. On the other hand, the two-layered candy retroreflector still had sufficient reflection strength to be effective as a camera marker after 60 minutes, although the reflection strength slowly decreased. Therefore, the two-layered candy retroreflector could maintain sufficient retroreflection for a long time even when it was in contact with the moist food.

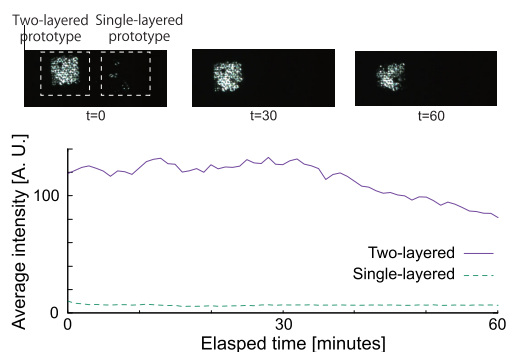


FIGURE 16. Average intensity profile of the light reflected by the prototypes placed on ice cream. The upper photographs are the observed images of the prototypes.

V. DEMONSTRATIONS

A. DYNAMIC PROJECTION MAPPING ON PANCAKES USING LUMIPEN

We demonstrated dynamic projection mapping to confirm that the candy retroreflector, as well as the conventional edible retroreflector made of agar [7], could be used as a marker for a camera to locate the object. The experiments were conducted using Lumipen [22], as in the case of the

previous study using agar. Lumipen is a projection mapping system using 1000 fps high-speed visual feedback and a galvanometer-scanner based high-speed optical gaze controller. The gaze controller can steer both the gaze direction of the high-speed vision system and the projection direction in several milliseconds by using automated rotational mirrors. By using this setup, the system can follow the marker recognizing in real time and project an image on the object continually. In this study, the projected object was a pancake, and the prototype single-layer candy retroreflector was placed on top of the projected object.

Fig. 17 shows the dynamic projection of a character on a moving pancake. When the pancake was moved, the projected character image also moved as if it were attached to the pancake. Therefore, it was possible to perform dynamic projection mapping based on the candy retroreflector placed on the circular pancake, as well as the agar retroreflector.

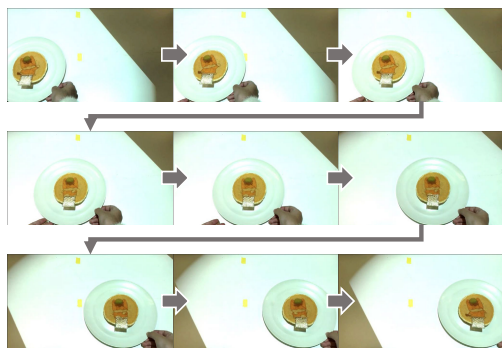


FIGURE 17. Sequence of photographs during the dynamic projection mapping on a shifting pancake. The projected character is Gunma prefecture’s mascot GUNMA-CHAN, permission number 2020-190095.

B. OPTICAL MOTION CAPTURE USING COMMERCIAL SYSTEMS

Many commercially available motion capture systems use retroreflectors as markers. We demonstrated that the candy retroreflector could be used as a marker for a commercial optical motion capture (MoCap) system (OptiTrack Prime41 and OptiTrack Motive Body). As shown in Fig. 18, we attached three single-layered candy retroreflectors to a shrimp cracker serving as the object so that the MoCap system could detect the position and orientation of the object. For the experiment, three cameras were used, placed as shown in Fig. 18. The system used in this experiment had infrared LEDs surrounding the cameras, and the light from the LEDs caused retroreflections that were used to detect the position of the markers. Normally, in the MoCap system, three or more cameras are placed around the object, and in this case also, the three cameras were placed parallel and adjacent to the object. The reason for this is that the range of possible retroreflective angles of incidence of the candy retroreflector is limited to around $\pm 45^\circ$.

The results of positional shift estimation are shown in Table 1. The estimated values were close to the true values, indicating that the system was able to recognize the

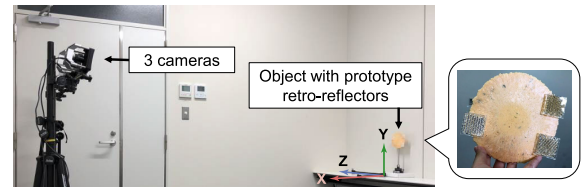


FIGURE 18. Photograph of the experimental setup for the optical MoCap experiment.

TABLE 1. Estimated positional shift in the case of Z-direction. The number of measurements was 500, and the estimated values are shown in the form average \pm standard deviation.

unit:mm	X	Y	Z
True value	0	0	10
Estimated value	1.18 ± 0.04	0.27 ± 0.01	7.0 ± 0.1

candy retroreflector as a marker and estimate the approximate 3D position of the object. Rotation angle estimation was also conducted. A rotation of 20 degrees around the Y axis was estimated as about 3.8 degrees. This large rotation estimation error could be caused by the arrangement of markers; all three markers were on the same plane, and such an arrangement of feature points is known to reduce the accuracy of rotation estimation [23].

For example, when conducting motion capture of animals, it is necessary to add markers to the animals, but sometimes the animals gnaw on the markers. In such cases, if the marker is made of food, it is expected to reduce health hazards to the animal.

VI. DISCUSSION

The two-layered prototype showed stronger retroreflection than the single-layered prototype. The reason is thought to be that the two-layered structure creates multiple paths for the retroreflected ray. Fig. 19 shows a schematic figure of ray paths. In this figure, the two-dimensional case is shown for simplicity. In the case of the single-layered structure shown in the Fig. 19 (a), the incident ray **R** is reflected at the bottom interface between the candy and the air. If the angle of incidence of the ray **R** to the boundary surface is small, a portion of the ray, indicated as **Ra**, is reflected and the rest portion is refracted out of the candy as the ray **Rb** according to the Fresnel equations [24]. And, only the Ray **Ra** contributes to the intensity of the retroreflection. In the case of the two-layered structure as shown in Fig. 19 (b), a portion of the refracted ray **Rb** is reflected at the surface of the bottom candy (**Rba**), and a portion of the ray **Rba** is refracted into the upper candy (**Rbaa**) and behaves as a retroreflected ray. Thus, not only the ray **Ra** but also the ray **Rbaa** contribute the retroreflection. Besides this, a portion of the reflected ray **Rbab** also contributes to the retroreflection through a similar process. Such multiple optical paths increase the efficiency of the retroreflection of the two-layered structure.

In this study, we used a commercially available corner-cube-type retroreflector in which the cubes had side lengths of 3 mm as a mold for forming a candy retroreflector.

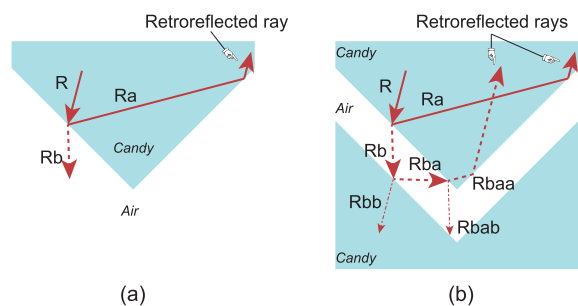


FIGURE 19. Schematic figure of the optical paths in single-layered (a) and two-layered corner cube retroreflector (b).

In principle, it is possible to make corner cubes of any size from candy. Increasing the size of the device can be achieved either by using a larger mold or by joining the devices in a tiled fashion. However, the minimum size is limited by the size of the single corner cube. In order to reduce the size, it is necessary to reduce the size of the individual cubes that make up the corner cube array. When we tried to make a prototype using a corner-cube-type retroreflector with smaller cubes, it was difficult to remove the air bubbles that accumulated in the corners when the candy was melted on the mold. To overcome this limitation, we are currently working on a method to remove bubbles using a vacuum chamber.

The candy retroreflector prototype used in this study showed uneven reflection strength, as can be seen from the images taken under coaxial illumination in IV-D. The reason for this is thought to be the inclusion of air bubbles during the fabrication process. Therefore, we expect that the reflection strength of the candy retroreflector will be stabilized by improving the air bubble removal method.

The prototypes reported in this paper achieved retroreflection at an angle of incidence of up to 45° . Due to this limitation, there were restrictions on the placement of the camera and the object in the MoCap demonstration described in V-B. Conventional MoCap systems use spherical markers whose surface is covered with bead-type retroreflectors so as to achieve retroreflection for incident light from all directions. Considering the corner-cube-type candy retroreflector proposed in this paper, it is expected to be able to achieve retroreflection for incident light from all directions by fabricating a polyhedron combined with corner-cube type retroreflectors.

The proposed retroreflector made of candy had a stronger reflection than the commercial glass-bead-type retroreflector. Considering the retroreflector made of agar that we reported previously [7] had a weaker reflective strength than the commercially available glass-bead-type retroreflector, the proposed candy retroreflector was stronger than the agar retroreflector. The proposed retroreflector also achieved longer lifetime of 10 days than the previous one made of agar whose lifetime was about 100 minutes. Therefore, a more practical edible retroreflector was developed.

As one of the potential applications, dynamic projection mapping on food was demonstrated based on the proposed

retroreflector. In this experiment, we assumed that the application would be for entertainment. However, the projection onto food can also be applied to its appearance control. Since the appearance of food affects its taste and value judgments, attempts to control them by using projection have been reported [3]–[5], [25]. Although the static appearance of the food alone affected the taste [4], the movement of the food, such as boiling appearance, also affects taste and value judgments [26], and a study to improve the taste by projecting a boiling effect has been reported [25]. Such appearance control of food is expected to be applied in various food service industries in the future, and projection is a suitable method for modulating the appearance of food. But it requires measurement of the position and posture of the food in order to project the image in accordance with it. The proposed method alleviates this difficulty and contributes to the realization of simple projection mapping.

From the viewpoint of biodegradability, the proposed method is also a way to create optical elements with lower environmental impact. Actually, in the field of electronics, sensors and robotics, where biodegradability has not been required in the past, research focusing on adding biodegradability has been reported [27]–[30]. In this paper, we focused on retroreflective materials, but a variety of optical elements such as lenses and prisms can be molded using the same manufacturing method. In the field of optics, the use of silk proteins as biodegradable material has been studied [15], [31], and this study focused on the use of sugars.

VII. SUMMARY

In this study, we proposed an edible retroreflector made of candy. As the possible structures, single- and two-layered structures were described. The materials were also investigated, and it was shown that reduced isomaltulose was suitable for fabricating the retroreflector. Two kinds of prototypes were fabricated and their retroreflection coefficients R were measured. The results showed that both types of retroreflectors had sufficient reflection strength comparable to conventional glass-bead-type retroreflectors. The two-layered structure indicated stronger retroreflection, and more stable against moist food. Thus, the two-layered candy retroreflector is more suitable for actual service applications. The prototype showed a much longer lifetime of 10 days than the previous edible retroreflector made of agar, and the lifetime is sufficient for culinary applications. The candy retroreflectors were also dry, easy to handle, and easy to store.

We also successfully demonstrated dynamic projection mapping on a pancake and MoCap system compatibility. The supposed situation of the dynamic projection mapping was a service in a theme park cafeteria where characters are projected onto the food. The use of the edible retroreflectors made it easier and cheaper to provide such services. Furthermore, the retroreflector made of candy is more versatile and practical, as it can be used in dry environments and in watery dishes. The proposed retroreflectors also worked as markers for the conventional MoCap system. Considering the MoCap

of animals, the markers made of food are expected to reduce health hazards to the animals even when they gnaw on the markers accidentally.

In the future, we will attempt to overcome the size limitation of the device and expand the range of applications.

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