interiqr: Unobtrusive Edible Tags using Food 3D Printing

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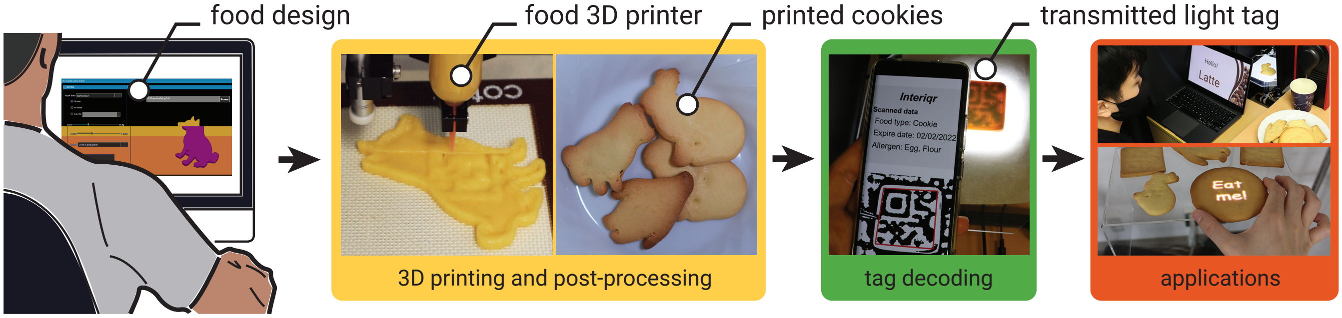

Figure 1: *interiqr* is a method that utilizes the infill structure of the 3D printing process to embed information inside the food, which allows for hiding the tag from the human eye. We present an end-to-end pipeline that allows the users to embedding data through food 3D printing and decoding them through several applications.

ABSTRACT

We present *interiqr*, a method that utilizes the infill parameter in the 3D printing process to embed information inside the food that is difficult to recognize with the human eye. Our key idea is to utilize the air space or secondary materials to generate a specific pattern inside the food without changing the model geometry. As a result, our method exploits the patterns that appear as hidden edible tags to store the data and simultaneously adds them to a 3D printing pipeline. Our contribution also includes the framework that connects the user with a data-embedding interface through the food 3D printing process, and the decoding system allows the user to decode the information inside the 3D printed food through backlight illumination and a simple image processing technique. Finally, we evaluate the usability of our method under different settings and demonstrate our method through the example application scenarios.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**.

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KEYWORDS

digital fabrication, food 3D printing, human-food interaction, invisible tag

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1 INTRODUCTION

Food tags have been widely used in many applications, whether to store the food data, identify the food source information, or improve the eating experience [1, 10, 23]. The tags are usually made of an embedded RFID and other sensors inside the food [8, 47] or printed on the packages [16, 41] so that they are less obstructive to the users but readable through machine-readable tags.

One key challenge in food tags is not only how to make them unobtrusive but how to make them edible so that users can freely consume the tags without harm or pain. To make them edible, researchers have utilized the material properties of food or physically modified the surface of food so that such artificial patterns could be used as tags. For instance, *Edible Retroreflector* [44] utilizes the reflection properties of food material to allow cameras to track and identify the location of the food, whereas *MetaCookie* [30] utilizes a branding iron to physically burn the surface of a food so that the burned appearance of the cookie can be used as a binary code. The previous attempts required either a specific food ingredients that limited the number of food materials or physical modification of the surface of the food, which could degrade its appetizing appearance [40].

With recent advances in digital fabrication that attempt to enhance cooking process [38, 49], researchers proposed hiding the actual amount of food by keeping the external shape as if it were a full infill, and utilizing the infill structure to maintain a stable shape without collapse through printing and post-processing [25]. Such approaches are unobtrusive and edible and can therefore affect its appetizing appearance less.

In this work, we propose an approach to generate food tags that allows to identify and embed information directly from inside the food, called *interiqr* (i.e., interior structure + QR). We integrate our food tags with the computational process that takes into account the infill parameters (e.g., volume and structure). When food is prepared for 3D printing (we refer to food 3D printers as 3D printers for the remainder of the paper), a computational process considers the amount of infill and their corresponding infill structure (as a food tags). If the amount of infill is high, the air space inside the infill is small, so that we generate the tag from multi-food materials. Otherwise, the tag is generated from the amount of infill and its air spacing. Since our approach modifies the infills with either infill structure or multi-food materials, it allows us to hide the tags from the user (Figure 1).

Our contributions can be summarized as follows:

- We present a method that combines the knowledge of digital fabrication and image processing to generate less obstructive edible tags using a food 3D printer.
- Through the experiments, we investigate the capability and limitations of our fabrication methods and discuss potential improvements.
- We demonstrate several use case scenarios of our edible tag that could enable new possibilities in human-food interaction (HFI) [3, 19].

2 RELATED WORK

In this section, we provide the background and review relevant related work on tags and food 3D printing. We start with some background on different types of tags, existing insights from prior attempts at digital fabrication for embedding information into food, and future opportunities for tags with food 3D printing.

2.1 Data Storage Tags and Identification Tags

Every tag contains some amount of information, whether its purpose is to store the data or to identify similar looking items. To provide a large enough capacity to represent the encoded message, the tag must have a large space. For example, matrix barcodes such as QR codes can store more information than 1D barcodes. On the other hand, not all tags are intended to store large amounts of information. For example, to identify similar looking items, it is often sufficient to extract a few features from the object, such as its physical appearance [11, 26].

In this work, we use the infill structure generated by 3D printing to store the binary data inside the foods. Because the infill structure is often sufficiently large, our method makes it possible to store either the data (e.g., hyperlink, date and time) or identification information.

2.2 Tags in Digital Fabrication

As also mentioned in the previous section, tags can be embedded in the food by using colors, surface, or internal geometry, and also by directly utilizing the materials substance.

The tags that utilize the colors or surfaces usually changes the visual appearance of the objects. *QKies* [12] directly color prints the food surface with QR tag patterns using edible ink. Similarly, *MetaCookie* [30] utilizes a branding iron to burn the food surface as an AR marker so that the surface appearance can be recognized using image processing. *Edible Retroreflector* [44] uses the reflection properties of food material (i.e., agar) that allows camera to track and identify the location of the food. Another approach to fabricate tags utilizes the materials substance, such as conductivity properties [13]. For instance, *Edible Electronic* [39] and *EdiSensor* [34] introduce a concept that utilizes the conductivity of food materials to identify, track, or embed the data. *Muffidgets* [14] investigates the food materials that can acts as the conductive elements for tangible interaction. Ishii et al. [15] present a method that adopts electrolysis effects to create color patterns on the food surface, which also have the potential to generate tags. Since these methods often utilize the surface appearance and food properties, the tags are usually visible, difficult to fabricate through commercially available food 3D printers, or requires connecting the external electricity to embed and recognize the information.

Besides edible tags, previous work in digital fabrication has utilized the surface geometry to fabricate *non-edible tags* that can identify the objects in a less obstructive way. Peng et al. [33] consider the directional light information to fabricate an unobtrusive tag so that the tag is only visible under directional light and invisible under ambient light. *Seedmarker* [11] proposes tag patterns that simultaneously fit to the patterns of the target objects the tag to be embedded. *G-ID* [6] uses the subtle pattern of a standard 3D printing process as a tag. Although the above methods might be applicable to food, the subtle pattern might removed after the post-processing, such as baking or cooling. Kubo et al. [20] utilize the resonant properties of the internal structure pattern generated with 3D printing software to identify the printed objects. *InfraredTags* [7] utilizes an infrared material invisible to the human eyes but recognizable by an infrared camera to print the QR tag inside the 3D printed object. A similar approach also uses a motion tracker in spatial augmented reality applications [35, 36]. *AirCode* [24] changes the internal structure of the 3D model to place air pockets beneath the surface so that the subsurface scattering can be used as a tag.

Unlike non-edible tags in which the material structure can be easily controlled through the printing process so that the tag can be fabricated with high accuracy. Our challenge is to generate tags that are not only edible and less obstructive (e.g., invisible), but also passively traceable and that can store and read the data. Inspired from previous work by using infrared technique to embed the tag [7, 24], however, the similar printing parameters cannot directly apply to our work as the absorption properties are different. Applying food-based materials requires a computational approach that allows adjusting the layer height for each food material so that the marker can be readable from the camera. Our approach contributes to the internal geometry embedding that considers the internal structure of the 3D object, material properties, and shape to embed the tags inside the food.

2.3 Opportunities for Tags in Digital Food Fabrication

Nowadays, a wide range of digital fabrication methods are used to enable different use cases with food, to assist the users in cooking the food and enable a wide range of interaction. For example, HCI researchers have begun utilizing the benefit of printing accuracy to generate food that would preserve its shape without support, thus creating a freeform and complex food that expands the design space for food interaction [28, 48], and using 3D printing to generate the food from a particular amount of energy users have been used at their exercise [17, 18]. Moreover, researchers have used the deformable materials with 3D printers to create food that can change its shape after fabrication when exposed to heat or water [32, 43, 45, 46].

Considering other aspects to provide a new eating experience and eating behavior, *Digital Konditorei* [50] presents a method to optimize the taste of food using a computational framework. Lee et al. [22] investigated the way to manipulate the food textures through the modification of the food internal structure by utilizing food 3D printing. *FoodFab* [25] introduces a framework that connects food 3D printers with perceived satiety in such a way that the amount of food could be reduced or increased depending on how hungry the person is, but the appearance of such foods should be the same.

In line with the previous food fabrication framework, we add the tagging system by considering how digital fabrication can transform the way Human-Food Interaction (HFI) occurs. For example, our system would allow *FoodFab* users to use the satiety parameters to generate food that embeds information about the actual calories or expiration date. Our system, adding to *Digital Konditorei*, would allows users to embed music related to the taste of the food.

3 EDIBLE TAGS EMBEDDING USING 3D PRINTING INFILLS

Our main contribution is a framework that allows the user to *embed* data into 3D printed food and then later *decode* data for their personal use through its food infills (Figure 2).

Our system *embeds* tags inside food by intentionally calculating the amount of infills and then generating the infill structures of an unmodified food shape and volume. For instance, if the users intend to print food with 100% infills, our system generates the tag by switching different materials with the same taste as the infills (see Section 5.2). Otherwise, if the infills are left inside the food (e.g., a user wants less food with the same appearance), our system generates the tag by considering the infill structure, which determines the printing patterns and generates the control file (i.e., G-code), where the printing extruder will follow (see Section 5.1).

Our system then *recognizes* the embedded data from the food tag that fabricated inside the food during the printing process. For example, after users take a picture of the food with backlight illumination, our system applies image processing techniques to extract and correlate the features with their internal structure to retrieve the data (see Section 6).

3.1 Choosing a Target Food

In principle, our approach is applicable to food that is printable with food 3D printers, that is the food that can be extruded through a syringe nozzle (i.e., food that grained with specific viscosity) and can maintain its structure after printing. We test our approach with *cookie dough* as the food material since prior experiments with food 3D printing [25] and food interaction [30] also used cookies. By using a common reference our results can add more directly to the previous food-interaction framework. The cookie dough is also easy to control in form and structure, even after printing. While realizing our method with cookie dough, we also do preliminary experiments with different food materials to show the possible applicability of our method to various food options (see Section 9).

3.2 Workflow for *interiqr* Systems

The *interiqr* workflow consists of a *tagging interface* and *recognition application*. We describe how we use (1) the tagging interface to assign each instance of a 3D printed food with a unique QR code prior to 3D printing, and how we use (2) the recognition application to recognize each food tag.

3.2.1 Tagging Interface. As can be seen in Figure 3, the tagging interface takes (a) the data to be embedded, and (b) the amount of infill (e.g., from 5% to 100%) as the inputs. In our example, we want to embed the "expiration date" into the 60% infill of a cookie; we then enter such information into the panel of the interface.

#1 Computing Infills to Generate Tag: We select 60% infills as the desired volume of cookie. Our software calculates the possible printing path that allows for creating the tag from the desired infills. Since the amount of infill is about half of its total volume, our software utilizes the air space and aligns the infill structure through the specific slicing parameters.

#2 Entering Data: Once the tag has been generated, we can enter the data to be embedded into the tag. The data can be in the form of a text, an image, or a URL. In our example, we embed the expiration date so that the user can know the expiration before eating the cookie.

#3 3D Printing: Once all parameters are ready, we click the "Generate" button so that the G-code file and digital markup file (XML) are generated. The XML file stores the tag information upon the data extraction through the applications. We can now send the G-code files to the 3D printer to fabricate the food with a tag.

3.2.2 Tag Recognition: Our system provides a stationary setup including the backlight illumination and camera. The user places the food on the plate with the light source on the back side. The system automatically captures the food from the top view, processes the image, and retrieves the embedded data. Similar to mobile applications, once the user captures the food, the embedded data are displayed on the screen. In this case, the expiration date of the cookie is presented to the user.

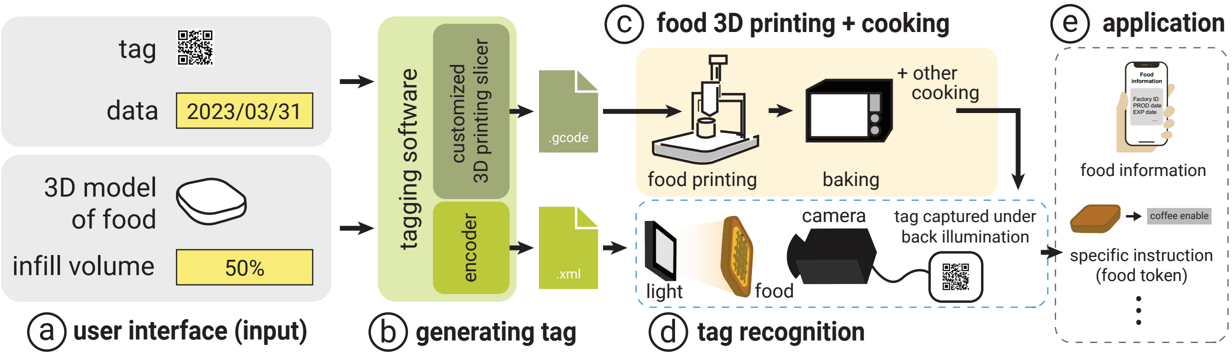
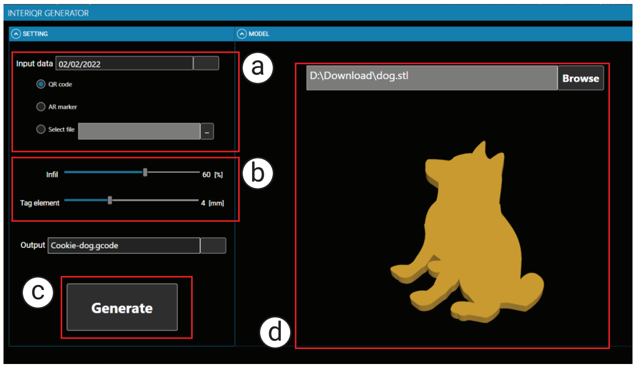


Figure 2: System workflow: (a) The system takes the tag information, food 3D model, and infill information as input. Then, (b) the system generates a tag by customizing the 3D printing slicer and output G-code file to (c) the food 3D printer. At the same time, the system generates an encoder file for (d) the recognition process. The 3D printed food is recognized through image processing, and (e) the food information is extracted along with other specific applications.


INTERIQR GENERATOR

SETTING

Input data 02/02/2022

● QR code

○ AR marker

○ Select file

Infil 60 [%]

Tag element 4 [mm]

Output Cookie-dog.gcode

MODEL

D:\Download\dog.stl

Figure 3: The *interiqr* tagging interface takes (a) data to be embedded, (b) amount of infill and size of tag (optional), and (d) food 3D model as inputs. Once the user presses the (c) generate button, the system embeds a tag inside the food 3D model and export the G-code to the 3D printer.

4 MATERIALS PREPARATION

The main challenge in preparing the food material (i.e., cookie) is the viscosity of the material, which affects the structure after printing. We conduct a simple experiment to examine the blending ratio of the materials so that the viscosity of the cookie dough is suitable for 3D printing. Thus, the shape of 3D printed cookie will looks similar to the input 3D model and the infill structure will be in the original input geometry. As shown in Figure 4, we heuristically calculate the ratio of flour, sugar, egg, and shortening, and we find that cookie dough with a 1.0 : 0.4 : 0.5 : 0.1 ratio (Figure 4c) is the best fit for our syringe-based 3D printer (Nordson EFD Automated Dispensing System). In particular, the structure of 3D printed cookie can keep its shape whereas the some part of the surface is collapsed, which we discuss the possible solution in Section 7.2. Once it is blended, the dough is rested in a fridge for an hour to allow it to set in its shape before being filled into the syringe (Nordson Optimum Syringe 20CC) and attached to the printer. The final viscosity of our cookie dough before printing measured with a viscosimeter (TGK TVB-10M) to confirm the stability of the blended ratio.

5 GENERATING TAG

Our tagging method utilizes the amount of infill to determine the desired tag fabrication, which is that (1) when the infills is less than 70%, we utilize the air space inside the food, and (2) when the infill is more than 70%, we utilize the secondary material, such as food with different colors to embed the tag.

Our software takes the 3D model of the food like a standard 3D printing slicer to generate the 3D printing paths. The slicer takes the target tag image (e.g., QR code or AR marker) and separately generates a printing path. Then, our software combines the top and bottom areas of the original 3D printing path with the 3D printing path of the tag image. Finally, our software optimizes the infill structure so that the infill volume fits the overall infill parameters.

As mentioned in Section 3, we use *cookie dough* as the target food to be embedded with a tag. The sample tag is a binary tag

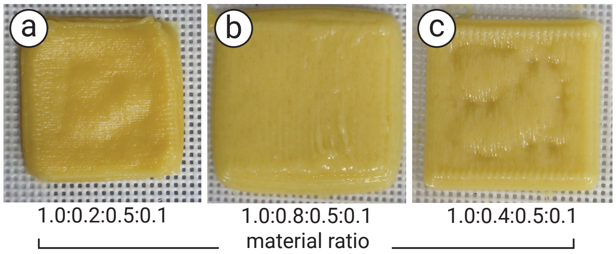
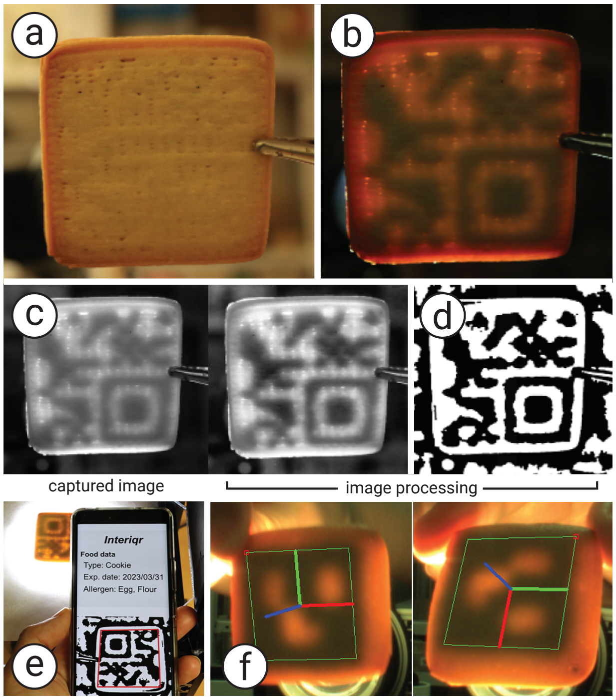


Figure 4: Result of the experiment to examine the blending ration of the cookie dough for 3D printing: (a) and (b) the mismatch ratio of flour, sugar, egg, and shortening; therefore, the printed cookie is too soft and cannot retain the shape, and (c) the suitable ratio of cookie dough for our 3D printing. The shape is stable whereas some part of the surface is collapsed due to the infill structure. The ratio of each cookie dough is shown below the image.



Interiqr
Food data
Type: Cookie
Exp. date: 2023/03/31
Allergen: Egg, Flour

Figure 5: Proposed method to generate and recognize a tag. (a) Cookie in a normal view without illumination, (b) cookie under backside illumination, (c) the image processing process to obtain (d) the binary code to recognize the tag using a mobile application. (e) The user can use a standard QR reader to recognize the tag and (f) obtained the data.

that consists of 13×13 modules (i.e., micro QR code), which can represent around six alphabet letters or ten of numeric [5]. The number of modules can be increased depends on the number of data to be stored.

5.1 Utilizing Infill and Air Space

In the case that the infill is less than 70% (i.e., some air space is requires inside the food), our method utilizes the infill structure (as a binary ”0”) and its air space (as the binary ”1”) generated by 3D printing to generate the tag. First, we calculate the amount of infill material that allows for generating a standard rectilinear structure. We then calculate the amount of material required to generate the tag. For example, assuming the size of the cookie is $5\ \text{cm} \times 5\ \text{cm} \times 0.8\ \text{cm}$, which requires 10 g of cookie dough to print with 100% infill, by setting the infill parameter as 70%, the required cookie dough for shells (i.e., the exterior of the cookies) is 2 g. The amount of cookie dough for the infill is $(10\ \text{g} - 2\ \text{g}) \times 70\% = 5.6\ \text{g}$. Therefore, we reduce the size of the internal structure to meet the required amount of infill (e.g., the fixed size of the tag). Finally, we combine the tag and shell before generating G-code to print with the 3D printer.

5.2 Using Multi-Materials

When the target 3D printed food has an infill greater than 70%, it is difficult to utilize the empty space inside the food to generate the tag. To tackle this issue, we print the infill with different materials. The infill material is selected under the certain conditions (see Section 7 for the details) so that it is easy to observe it through the camera and enclose it with the standard material. The secondary material is act as a binary code ”1”, while the standard material is act as a binary code ”0”. For example, in our case, we experiment with cookie dough mixed with black food coloring so that it can be used as the tag but still taste the same. Therefore, our tag is stills less obstructive to the users (Figure 5a), even it is printed with colored materials.

6 RECOGNIZING TAG

As shown in Figure 6, to recognize the tag, the cookie is set under the bottom illumination setup facing a camera (MQ013CG-ON, Ximea camera) setting on the top. Note that, the backlight illumination can be either visible light (e.g., white light), invisible light (e.g., infrared light; see Section 7.1.1 for the details) or with spatially coded light. In our sample, we use a projector (PJ WXC1110, RICOH) for the backlight illumination, which allows us easily to control the light intensity and colors. We also use an infrared backlight illumination (Advanced Illumination Backlight, 880 nm) for the infrared light source. The captured image is obtained in grayscale, applied with an *adaptive histogram equalization* (CLAHE) filter to increase the contrast, and then with *Gaussian blur* to reduce the noise (Figure 5c). Then, the image is converted to a binary image using the *adaptive gaussian threshold* method to obtain the shape of the tag (Figure 5d). The QR codes can be recognized through the standard QR library (e.g., QRQR, DENSO WAVE). In our example, we also used an *ArUco* library to recognize the ArUco marker. Figure 5e and 5f shows the decoding situation using the QR library and decoded result using the ArUco library for the 3D position tracking application.

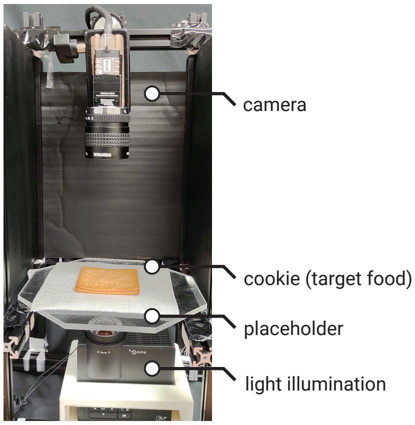


Figure 6: Tag recognition setup: The projector is used to illuminate the cookie from the bottom, and the camera captures the image of the cookie from the top.

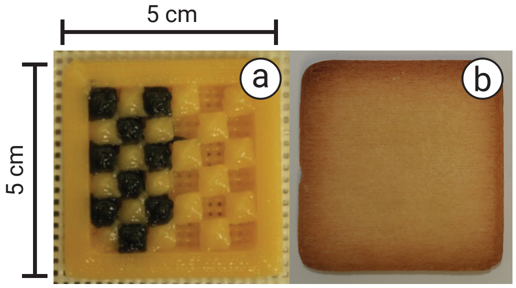


Figure 7: Experimental setup: (a) cookie filled with black material and air spacing in a checkered pattern, and (b) after being enclosed with layers 1.5 mm in height and baked.

7 EXPERIMENTS

We conducted several experiments to evaluate the readability of our edible tags, and to verify the feasibility and scalability of our method.

7.1 Tag Readability

We investigate the readability of the tag under different backlight illumination conditions, and with a specific light spectrum.

7.1.1 Transmission Spectra. As mentioned in Section 6, our system utilizes back illumination to recognize a tag from the captured image of the tag. The light is transmitted through the cookie and captured by the camera. Therefore, the area that does not block the light, that is air space could be transmitted across surface better than the area that has food materials of infill structure, which blocks the light. Moreover, the spectrum of light also affects how the visible light is transmitted through the food materials. Selecting the correct band would allow for improving the readability of the tag. To understand the effect of transmission spectra, we conduct an experiment with various light spectra to understand the transmission properties of our tags. We use a spectroradiometer (SR LEDW, TOPCON) to measure the transmission spectra of cookies printed with air space, regular material, and black material, respectively. In this experiment, we 3D print a cookie with a checkered pattern, where the infill is filled with black material on the left half and air space on the right half (Figure 7a). The infill is 1.5 mm in height, enclosed with top and bottom layers of the same height, equaling 2 mm. The light illuminates the backside of the cookie, and the spectroradiometer captures it from the front side.

Figure 8 shows the measured transmission spectra. We find that with light from a wavelength of 550 nm to 780 nm, the area with air space appears brightest compared with the area with black cookie dough and regular cookie dough, respectively. In particular, a specific wavelength at 680 nm (red light) increases the contrast of the captured tag with air spacing, black cookie dough, and regular cookie dough. We capture the tag from different camera distances from 15 cm to 30 cm and find that the image captured from as far as 21 cm for air space, and 24 cm for black cookie dough, from the tag can be recognized with our software.

Although the purpose of this experiment is to understand the transmissive spectra of backlight illumination in a visible wavelength, we also experiment with invisible wavelength at 880 nm (infrared light). As shown in Figure 9, the embedded pattern of the food tag printed with air space and illuminated under infrared light (Advanced Illumination Backlight, 880 nm) can be captured by an infrared camera (MQ013CG-ON, Ximea camera with visible-cut/infrared-pass filter HWB800), and is recognizable through the same image processing software. Unfortunately, the infrared light is not transmitted well through the black cookie dough due to the absorption of the infrared spectra. We will explore the absorption space that could provide the different infrared absorption spectra. For example, the components inside the food such as proteins, glucose, sucrose, and water [2]. Utilizing such food components as an infill could potentially create infrared tags.

7.1.2 Separation of Transmissive and Scattered Light. The captured image of the tag embedded inside the cookie contains both transmissive and scattered light. Whereas the transmissive light is directly transmitted through the infill structure, the scattered light degrades the transmitted image and reduces the readability of the tag. In particular, the food tag printed without air space usually contains scattered light, which degrades the readability of the tag. In this experiment, we extract the transmissive light by leveraging a decomposition method using *high-frequency illumination* [31] and measured the readability of the tag.

We replace the white light illumination with a checkered pattern projection that shifts its phase multiple times during the image capturing process (Figure 10). At each phase, we captured an image of the cookie and calculate the maximum L_{max} and minimum L_{min} value of each pixel among the captured images. The decomposed transmissive and scattered lights are as follows;

$$L_t[c] = L_{max}[c] - L_{min}[c] \tag{1}$$

$$L_s[c] = 2L_{min}[c] \tag{2}$$

where L_t is the transmissive light, L_s is the scattered light, and c refers to an image pixel.

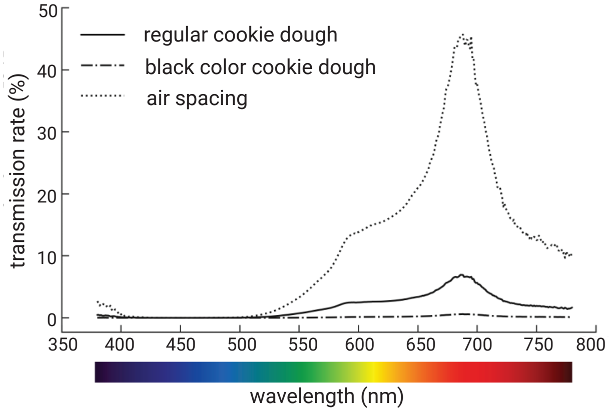


Figure 8: Transmission spectra of different infills including regular cookie dough, black color cookie dough, and air space.

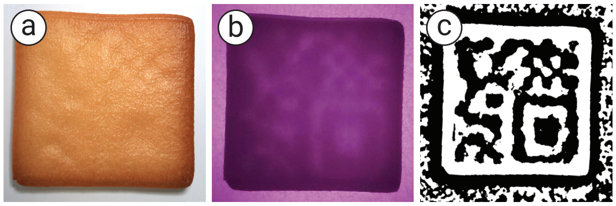


Figure 9: Back illumination with infrared light: (a) the user's naked-eye view, (b) the food captured under infrared camera, and (c) the image processing to recognize the tag.

The results are shown in Figure 11. We also conduct the same procedure from the above experiment by capturing images of tags from different distances. Overall, a tag can be easily recognized with our software when no scattered light is present. We find that by separating the scattered light from the transmissive light, the readability of tag with our software is improved from 21 cm to 23 cm for air space, and 24 cm to 29 cm for black cookie dough. In addition to the air space and multi-material printing, we combine both methods by printing tags using multi-materials with 1 mm air space. We find that with this method, a tag can be recognized from as far as 35 cm can be recognized with our software.

7.2 Tag Concealability

Altough our aim is to embed the tag inside the food so that it is less visible to the users, one of our methods that utilizes air space inside the food makes the embedded tag visible from the outside due to the expansion of the air during the baking process. The surface of the air spacing area is raised, making the shape of the tag appear (Figure 12a). In addition, printing cookie dough over the air space caused the dough to drop, thus making the shape of the tag appear after baking.

Although we can prevent the expansion of the air by 3D printing the cookie on a mesh baking sheet, and add *small holes* at the bottom of the cookie (Figure 12b), some areas still rise or drop during baking. To solve this issue, we propose a method that creates a small support over the air space to prevent the rising and dropping during baking. At each air pocket, we print a 0.6 mm line of cookie dough to support the hanging surface. We conduct an experiment that compares the selectively created supports over the large air spacing area with full support (i.e., support over all air space), and without support (i.e., näive). As shown in Figure 12, we find that selectively creating supports over air spaces that larger than 16 mm^2 prevents the dough from rising and dropping and maintains the readability of the tag by the software compared with full support that takes more time to print and the small holes that show the shape of the tag.

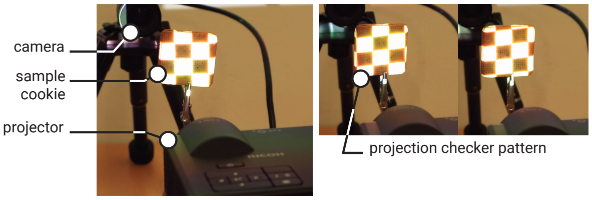


Figure 10: Checkered illumination setup to separate the transmissive and scattered lights (left), and the sample of projection image (right).

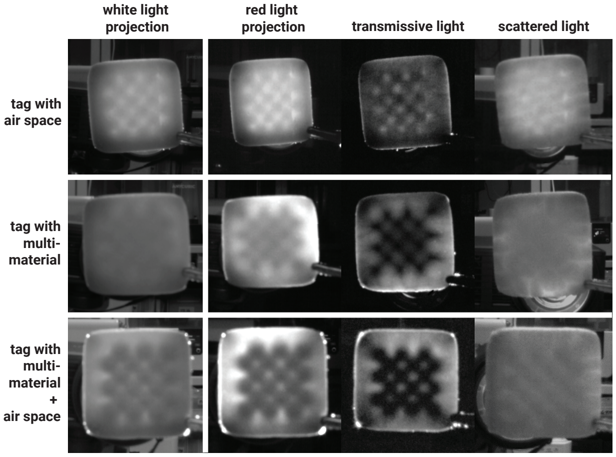


Figure 11: Results of tags captured under transmissive and scattered light separation method with various infills.

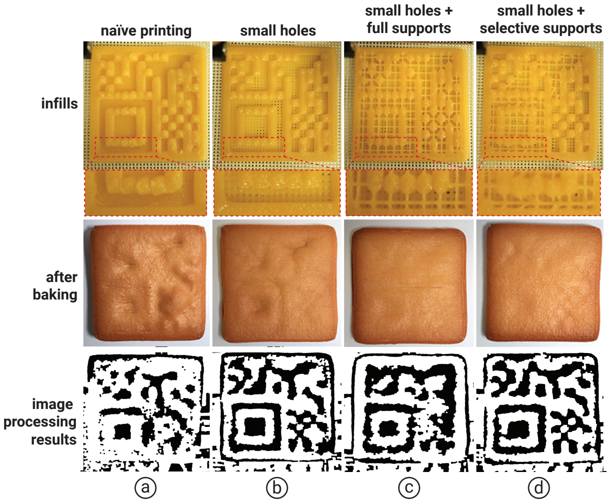


Figure 12: Results of adding the selective printing of supports over the hanging surface compared with (a) näive, (b) small holes at the bottom of cookie, and (c) small holes with full support, respectively.

7.3 Minimum Tag Size

Since our tagging method utilizes the amount of infills, it is possible that the tag will not cover the size of the cookie but might be attached to some part of the cookie. Therefore, it is important to understand the capability of our tagging method to produce a tag with the different size. In our case, the standard size of a tag that is 100% readable at 15 cm distance is 4 mm square for one module, which is 52 mm × 52 mm for a micro QR code (13 × 13 modules) and 24 mm × 24 mm for an ArUco marker (6 × 6 modules). We reduce the size of a tag to 3 mm square, and 2 mm square, respectively, for one module, which is 39 mm × 39 mm and 26 mm × 26 mm for a micro QR code and 18 mm × 18 mm and 12 mm × 12 mm for an ArUco marker, respectively. Whereas the 3 mm square tag is readable from the same distance as the 4 mm square tag, the tags printed with a 2 mm square module requires capturing the image of the tag at an 8 cm distance. Moreover, the tag does not adhere well to shells during the printing process, which makes the fabrication process more difficult. Therefore, we conclude that our tags are printable and readable when the size is at least 3 mm square for one module with a 0.6 mm nozzle.

For the thickness, we test the tag with different thickness. While the tag can be produced with at least 2 mm to 7 mm thickness, our study found that the 7 mm thickness makes the readability of the tag unstable, and the 2 mm thickness makes the printability of the tag unstable. We found that 5 mm would be the standard height, which does not affect either the readability and printability issues.

7.4 Safety and Eating Experience

One of our goal is to print an edible tag so that users can safety consume the tag while enjoying the eating experience. We describe our setup in terms of safety factors of our fabrication process, and conduct an experiment to verify how the user can enjoy the eating experience.

For the food safety, our fabrication pipeline uses a one-time food-dedicated syringe and oil-free air compressor (California Air Tools 10020C) as the 3D printer components to reduced the number of infected bacteria and other artifacts during the printing process. In addition, we conduct a fabrication experiment under the regulation of our local university.

For the eating experience, we conduct a pilot study in which 9 participants (aged between 21-35 years old) recruited from a local university are asked to eat a 3D printed cookie with a tag embedded using (1) infill and air space, and (2) multi-materials (e.g., tag created from black food coloring) compared with a cookie printed with 100% infill as the baseline. Note that the participants do not know the condition of the infill structure of each cookie because the cookies look similar from the outside. They are asked to rate the mouthfeel (see [29] for more details) in terms of the dryness, hardness, smoothness, suppleness, and sweetness, respectively, between three different cookies using a 7-point Likert Scale to determine the similarity of the eating experience. The experimental protocol has been approved under the Institutional Review Board (IRB) of the local university. In short, we find that the participants feels the three types of cookies have a similar eating experience. As shown in Figure 13, the participants experience all types of cookies as similarly dry (avg. 5.5, 5.4, and 5.1 for 100% infill, air space, and multi-material, respectively). Also for smooth (avg. 3.1, 2.8, and 3.3), supple (avg. 3.3, 3.2, and 3.25), and sweet (avg. 4.3, 4.0, and 4.1). However, the participants perceive a difference in hardness between infill and air space cookie (avg. 4.35) and multi-material cookie (avg. 6.1) compared to 100% infill cookie (avg. 6.5) due to the different infill structure of each cookie.

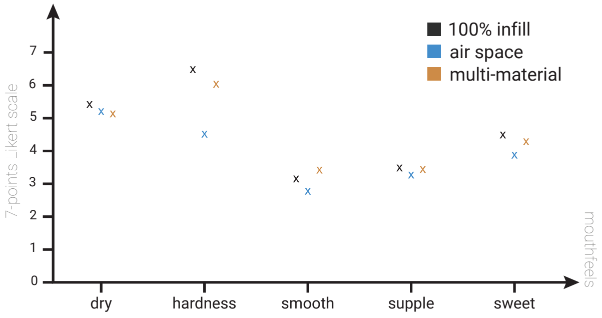


Figure 13: Results of eating experience experiment comparing two different tag embedding methods with 100% infill cookies.

8 APPLICATION SCENARIOS

We demonstrate the application scenarios by which *interiqr* would potentially contribute to society.

Food Interactivity: *interiqr* can be used as an interactive marker for spatial augmented reality systems [4]. The embedded tag is recognizable by a projector-camera system to digitally augment food, which allows the user to experience food beyond its materialistic flavor, or to create a food artifact as a display over the real food. Similar to *Edible Reflector* [44], we can dynamically project artificial patterns such as a trademark or specific information to improve the eating experience (Figure 14a). Since our tag is embedded inside the food, it does not requires additional food for the markers. Our method would also be compatible with an application from *metacookie* [30], although in our application, the surface can also be used as the projection surface. In addition, the embedded tag can be used as an edible controller; the user can use the food as a game controller before consuming it after finishing the game play (Figure 14b).

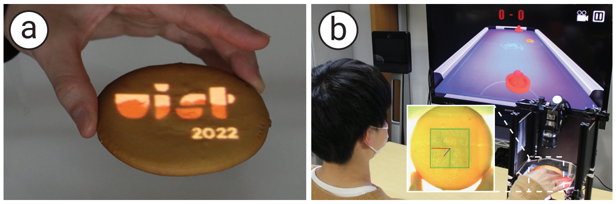


Figure 14: Food interaction with *interiqr*: (a) augmenting food through an augmented reality display and (b) game controller using an embedded food marker.

Food Traceability: The tag embedded inside the food can be used as a token to automatically select the recommended drink for each individual user. For instance, the user can place the cookie embedded with a tag on a placeholder, and the recommended coffee will automatically be brewed (Figure 15). The *interiqr* can also be used to create identifiable food categories as part of the storage and packing process. Moreover, understanding the types of ingredients would help users with food allergies to avoid such food or to make sure that the food fits their health condition. As shown in Figure 1, the embedded tag can be used to notify users about the food information. The embedded tag can also be used as part of an eating support system in which a robotic arm assist the user in eating the food [27]. For example, the tag embedded inside the food is identified by the robotic arm to adjust the feeding speed to the user based on a specific food ingredient or viscosity. In this way, the user can enjoy with food without choking.

Figure 15: Food traceability with *interiqr* can be used as a food token to know the origin of the food and recommend a drink to pair with food.

Other Possible Scenarios: Beyond the applications described above, our method can also be used for the following scenarios; First, our method can also embed text and a natural image other than a binary code in a cookie (Figure 16), which could be revealed once the cookie is hydrated (e.g., after dipping in tea). Thanks to the waterborne light rays having a better chance of penetrating the surface of a cookie and traveling within it [37]. Second, we can utilize the layers of structure in which two cookies can be stacked together to create new information (e.g., the different tags), which can be used as a social food interaction aspect. Third, we can embed different tags in several parts of a cookie to be used as different parts of information. Once a user bites a part of the cookie they can reveal a piece of the secret message. Thus, our food tag enhances the appetites and motivation of the users. Finally, we can utilize a food material whose light transmission property changes over time, e.g., sweet potato. Once time is passed the transmission property of the sweet potato changes through dehydration. Thus, fresh cookies and old cookies can be read as different data with the same print.

Figure 16: Our method can also embed a text or natural image other than a binary code.

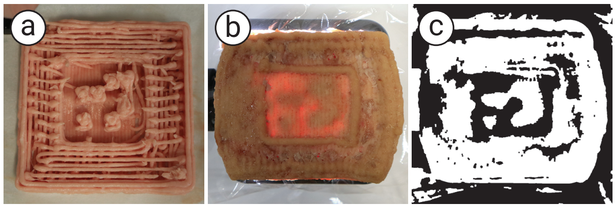


Figure 17: 3D printed meat with a tag. (a) The outlook during the printing process, (b) the meat under back illumination, and (c) the image processing result.

9 DISCUSSION AND LIMITATIONS

We discuss limitations and future work that would potentially improve the tagging of data on food using 3D printing.

Applicability Beyond Cookie Dough: In this work, we focused on cookie dough to demonstrate our method because it can easily grained with specific viscosity, maintain its shape and structure even after printing. We believe that different slurry-based materials are applicable to our method as long as the materials can form into a certain shape after printing and are capable of back illumination. In our preliminary attempts, we found our method could embed air space tags in avocado, mashed potato, cream cheese, and meat. As shown in Figure 17c, the meat printed with an embedded tag can be recognized through our decoding software. However, the recognition is unstable due to the formation of the infill structure after printing. Moreover, post-processing (i.e., oven baking) shrinks the meat (Figure 17a and 17b). We believe that understanding the rheology of food materials is necessary in order to optimize the infill structure to fit the printed results. For example, instead of printing with a straight line, a specific path might be necessary to obtain a straight line after post-processing. Furthermore, it is also possible to utilize multi-material techniques to adjust the viscosity of the slurry-based materials such that its shown in the previous plastic-based 3D printing [42]. We will further experiment with different types of food materials in our future investigations.

Applicability to Other Production Methods: Our work only demonstrates the direct 3D printing method as one of the possible personal fabrication pipelines that allow the food to be tagged. We believe that another fabrication method such as 3D printed molds [21, 50] and laser cutters [9, 30] can be used to fabricate tags. Molding would increase the embedding speed of the tags for mass production, and laser cutters would increase the number of applicable food materials to be used with our recognition method including the ready-to-eat foods.

Information Capacity: Our sample embedded the QR codes with 13×13 modules and the AR markers with 6×6 modules, which can embed six alphabets and the IDs. Increasing the information capacity is possible by employing larger size of tags such as a QR code with 21×21 modules. However, there were inherent limitations on the printing form factors and food materials that affect the embedding process with larger tags. The longer printing time leads by the larger data embedding, which makes the outer shell collapse as the food material properties are changed. On the other hand, we can reduce the size of module to print a larger capacity in a small size of food. Our minimum module size to create a stable readable structure is 3 mm square so that at least 63 mm square (3 mm × 21 modules) is required to embed an edible QR code (version 1). Using a nozzle smaller than 0.6 mm could allow for creating a stable structure with a smaller space, but the number of materials that are applicable with such a nozzle size is also limited. For instance, it might not be possible to print meats or vegetables with particles larger than the size of the nozzle.

Visibility of Back Illumination: Although our technique is compatible with backlight illumination in both the visible, invisible spectra, and with spatially coded pattern, it works better with food tags printed with air space. In most cases of multi-material printing, our current recognition technique requires the backlight illumination setup in the visible spectrum. Therefore, the tag can be slightly seen by the users during the recognition process. To solve this issue, the infill materials require further experiments to find the corresponding transmission spectrum in an invisible region (i.e., infrared spectra) for each different material, which we expect to examine in future work. For the workaround, we can embed alternative tags such as texts and binary images instead of actual tags to increase the naturalness of the tag that is being seen by the users.

10 CONCLUSION

In this paper, we present a method that utilizes the infill structure in the 3D printing process to embed information inside the food that is difficult to recognize with the human eye, called *interiqr*. Our key idea is to determine a way to embed edible tags, whether with air space inside the food or with secondary materials, and to generate a specific pattern inside the food without changing the food geometry. Thus, *interiqr* does not add any artificial materials to the food but exploits the patterns appearing as hidden food tags, adding to a HFI pipeline. We also demonstrate suitable application scenarios and evaluate the accuracy under different printing parameters.

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