Proposal and Evaluation of the Utilization of a Baking Method to Apply Visually Unrecognizable Two-Dimensional Code onto Valuable Ceramic Products

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Abstract

We have proposed two techniques for identifying valuable ceramics. The first one involves baking visually unrecognizable two-dimensional code onto each product during the manufacturing process. This very thin code is made from transparent glass phosphor and is placed between the clay and glaze layers of the ceramic product. The second one involves extracting the information from each product with the said code in a non-contact manner by acquiring and processing images. The QR (Quick Response) code images are taken by an infrared camera and light.

Keywords: ceramics, QR code, steganography, glass phosphor, artifact-metrics, image processing.

1. Introduction

1.1 Background and Aim

Fine craft products are different from ordinary personal items used in daily life, as they are elaborately designed with beautiful patterns and colors. These products are sometimes related to intellectual and esthetic hobbies; examples include textiles, pottery, porcelain, lacquer, and wooden works. The production of fine craft products is costly and time consuming. Specifically, ceramics produced by renowned artists and manufacturers are likely to have high prices, which causes them to be more carefully handled than ordinary ceramics and passed on to following generations. In Japan, the abovementioned ceramics are preserved in wooden boxes paired with the products⁽¹⁾. On the surfaces of

such a box, product-related information, such as the title, name of the artist or manufacturer, and production date are written (so-called “Hako-gaki” in Japanese), so that everyone can know the product information⁽²⁾.

An artist or manufacturer will sometimes receive a request from a customer to make a new box and to write the product information on the new box because of loss of the original, aged degeneration, or defacement as the product and box are physically separable and the box is organic while the product is inorganic. An artist or manufacturer who honors such a request will make a new box and write the product information on it after authenticating the product. However, it is quite difficult to correctly obtain this information from the original box if it is lost or its surface is significantly degenerated or defaced.

To prevent such problems in the future, unifying products and their information (by recording product information on products themselves during the daily routines of artists or manufacturers) and a method of correctly extracting such information from products are necessary. Such a method would facilitate product identification and the writing of product information on new boxes. Two technical points must be addressed to realize the abovementioned idea. One is to develop the technology necessary to record product information on ceramics without ruining their designs, as each product has patterns and colors generated by clay, glaze, and paint. The other is to establish a contactless technique capable of correctly extracting product information while avoiding causing physical damage, such as scratches and stains, to products.

We herein propose two techniques: (1) a method that can

Fig. 1. Outline of artifact-metric system.

bake transparent and thin two-dimensional code onto ceramics and (2) a method that can extract product information from such code by taking and processing images.

1.2 Related technique to authenticate valuable ceramics

We have proposed a technique to mechanically authenticate valuable ceramics⁽³⁾. In this method, characteristic information that is spontaneously and accidentally generated during the manufacturing process is stored in a secure database beforehand. To authenticate a product, characteristic information is extracted from the target product and compared with the stored information. This kind of technology is called artifact-metrics, and the corresponding system is called an artifact-metric system (see Fig. 1).

In artifact-metrics, a material with specific optical, electrical, or electromagnetic characteristics is added to the product to extract the characteristic information easily. In our method⁽³⁾, an acquired infrared (IR) image is used, which indicates the intensity of IR emission of the material by optical excitation. In contrast to traditional characteristic information, the characteristic information of artifact-metrics is spontaneously and accidentally generated during the manufacturing process. However, in the current study, our objective was to create both character and characteristic information on the ceramics during the manufacturing process.

2. Basic information, Prerequisites, and Requirements

After introducing the ceramics manufacturing process, we specify the prerequisites for understanding the scope of this study and list the requirements that our techniques should satisfy.

2.1 Basic information

Fig. 2. Fabrication processes (4) through (8).

Fig. 3. Pattern baking method using transfer paper.

Ceramics are produced through eight processes: (1) crushing raw materials, (2) material refinement and clay making, (3) shape forming, (4) biscuit firing, (5) glazing, (6) firing, (7) painting, and (8) final firing. Fig. 2 shows procedures (4) to (8) using a representative white plate. The biscuit plate is fired after glaze drying. The glaze coats the whole plate with a smooth surface, which is good for painting, by vitrification. In the painting process, patterns are depicted with paint brushes or transfer paper⁽⁴⁾. The product is completed after painting and a final firing at a lower temperature.

The advantage of using transfer paper is that patterns are depicted and baked at low cost with high definition and high speed. Fig. 3 shows the method used to transfer a pattern onto a ceramic piece. First, the pattern is printed on a transfer sheet by using screen-printing and painting ink. Next, the transparent resin layer with the printed pattern is peeled and separated from the transfer sheet while soaking in water. This resin layer is pasted on the ceramic piece and dried after the first firing. After the second firing, only the ink remains, and it forms a pattern on the surface of the glaze layer as it undergoes vitrification during firing. The thickness of a baked pattern is approximately 10 μm .

2.2 Prerequisites

To clarify the scope of this discussion, we note the following points:

- To avoid future occurrences of the problems described in section 1, we focus on products produced daily by artists and manufacturers.
- Although we are considering applying our techniques to both pottery and porcelain, in this paper, we only discuss its feasibility for use on porcelain plates.
- We adopted QR code as a type of two-dimensional code, as it is popular around the globe and has high error-correcting capabilities. Thus, its information can be extracted in a simple manner (image acquisition) and physical damage, such as scratches and stains on the products, can be avoided while extracting contrasting information with electrical or electromagnetic ways.
- We used a transfer sheet to bake thin QR code at a low cost with high definition and high speed.

2.3 Requirements

In this section, we indicate three requirements that our proposed techniques should satisfy.

Requirement 1 (Effect on colors): “The risk of effects on colors derived from clay, glaze, and paint is low when QR code is baked on a plate.” This requirement is necessary because product colors should not be impaired as a result of the QR code baking process.

Requirement 2 (Difficulty of visibility): “It is difficult to visually detect differences between plates with and without QR codes with the naked eye.” This requirement is necessary because the product design should not be impaired because of the existence of baked QR code.

Requirement 3 (Information extraction): “Related information can be extracted correctly from the plate labeled with QR code.” This requirement is necessary because the shape of the QR code should not be lost during the manufacturing process and the product information should be extracted correctly from the photographic image.

Requirement 4 (Availability of artifact-metrics): “Photographic images of QR code are available as characteristic information for the artifact-metrics technique.” This requirement is necessary because the objective is to have both types of information (textual information for products and characteristic information for identification) on the ceramics.

Fig. 4. Glass phosphor emits near-IR light following optical excitation.

3. Our techniques

In this section, we propose our techniques that satisfy the requirements described in section 2.3 and realize the idea presented in section 1

3.1 Production of QR code

To bake thin and transparent QR code onto the ceramics and image it photographically, we chose to use transparent glass phosphor that emits near-IR light following optical excitation; we decided to use this material powder as the ink pigment for painting to print QR code on the transfer paper. Our glass phosphor (shown in Fig. 4) was transparent and had a high IR conversion efficiency, but exhibited pale blue. In regard to this point, we conducted another experiment with a white pottery plate and transparent glaze (which formed a transparent glassy layer after firing) and found that the existence of glass phosphor particles was difficult to detect with the naked eye. The plates emitted near-IR light well following optical excitation when even tiny amounts of particles were added on their surfaces⁽³⁾. Accordingly, we concluded that this material would likely be capable of realizing our idea.

3.2 Baking of QR code

By using transfer paper, the thickness of baked QR code is approximately 10 μm . However, this value is the limit at which fine particles can be detected by the naked eye⁽⁵⁾. Furthermore, code of this thickness could scatter light, enabling it to be distinguished. Accordingly, developing the necessary technique to differentiate the above code is difficult. We established a technique that includes pasting the transfer paper's resin layer with printed QR code on the biscuit layer and thickening the transparent glaze layer formed on the biscuit layer twice (see Fig. 5). Accordingly, distinguishing the existence of QR code is physically and optically difficult, as the thickness of QR code can be reduc-

Fig. 5. Schematic of baking QR code porcelain product.

Fig. 6. Acquisition of QR code images.

ed because of melting of the glass phosphor and glaze with affinity because of its glassy feature. Although glass phosphor is a stable oxide and does not have any negative effects on the human body or the environment⁽³⁾, covering QR code with a glaze layer can ensure reliability and maintain the facility of connecting the consumer to the product.

3.3 Photographic imaging of QR code and extraction of related information

In the proposed method, the glass phosphor included in the baked QR code is excited by using a light source that can irradiate light with wide angular distribution. An IR camera is used to image the glass phosphor when it emits IR light to obtain the QR code image (see Fig. 6). The product information can be obtained by using image processing software that can extract character string information from an image containing QR code after appropriate preprocessing.

4. Experiments

In this section, we describe several experiments that were conducted to verify the feasibility of our techniques and discuss their results.

4.1 Production of QR code

We followed the general method of ink-making for transfer paper and fabricated a transparent ink that contained fine glass phosphor particles (equivalent to the pigment of ordinary ink) and the vehicle (the liquid for pigment disper-

Fig. 7. Images of generated QR code (left) and QR code printed on transfer paper (right).

Fig. 8. Product information storage method.

sion that contains the resin and solvent). The weight ratio of the particles to the vehicle was 1:1. Next, we referred documents that describe QR code⁽⁶⁻⁷⁾ and produced the code with version 1 (21 cells), error correcting level L (data restoration rate 7%), and cell size 3×3 pixels (see Fig. 7: left). It had the character string “Fuchi.” There is a correlation between the version and the error correcting level—the code can contain up to 25 alphanumeric characters. We printed the reduced-size QR code on the transfer paper fitted with a 10.5 mm square (see Fig. 7: right). Generally, the smallest size of the seals made on fine craft products, including ceramics, is 10.5 mm⁽⁸⁾.

It is difficult to store the entire product information directory in this QR code, as it can only store up to 25 alphanumeric characters. We, therefore, proposed the solution of constructing a secure web server to store all of the product information and using a string of short URLs⁽⁹⁾ without “https://” in the QR code (see Fig. 8) to refer to the product information via the Internet. Accordingly, users could refer to the product information with their electronic devices. In this elementary experiment, we used a small QR code to determine whether our technique was feasible. However, we do plan to expand the size of this code so that it can store more information.

4.2 Baking of QR code

Firstly, we prepared a white biscuit plate. We chose this

Fig. 9. Images of porcelain plate without QR code (left) and with QR code (right).

Fig. 10. QR code was baked in red-dashed frame.

plate to confirm the satisfaction of requirement 1 described in section 2.3. This plate can help verify whether the pale blue from glass phosphor affects the color of white clay (meaning whether the pale blue is distinguishable after firing). Next, we soaked the transfer paper (described in section 4.1) in water to peel off the resin layer, pasted it in the center of the biscuit plate, and allowed it to dry. The operation (described in section 3.2) to increase the thickness of the transparent glaze layer was performed by soaking of the plate in the glaze again and drying it a second time. The transparent glaze was white before firing, but it did not hinder the verification, as the color became clear and transparent after firing. During the firing process, after setting the plate into the furnace, we gradually raised the temperature from room temperature to 800 °C within 2.5 h. That temperature was maintained for 10 min before slowly cooling over 1.5 h.

Fig. 9 shows the plate with and without the QR code. No obvious difference in outward appearance is evident. Fig. 10 shows the 10× magnified image with baked QR code taken by the microscope. A 10-mm-wide paper clip was set on the plate to indicate where the QR code was baked. It was baked in the square outlined by the red-dashed line, however, the existence of the QR code and the pale blue color from the glass phosphor were visually undetectable.

4.3 Difficulty of QR code visibility

To confirm the satisfaction of requirement 2 (Difficulty of visibility) described in section 2.3, we prepared three plates with baked QR code (using the method described in section 4.2) and three plates without baked QR code (meaning the resin layer was not pasted on the plate). We only placed spots on the reverse sides of the former plates. Next, we gathered 30 examinees and conducted an experiment based on the following guidelines and calculated the correct answer rate of each examinee.

- (1) The examiner explained the existence of two types of plates (with and without QR code) and did not mention where the QR code was baked.
- (2) The examiner selected two plates from six randomly arranged plates (where the plate-selecting operation could not be seen by the examinee) and put them on the table in front of him or her.
- (3) The examinee observed two plates for 15 s with the naked eye (during that time, the examinee was not allowed to see the reverse sides of the plates) and answered what kind of pair was shown below on the table.
 - (A) A pair with and without QR code.
 - (B) A pair with QR code.
 - (C) A pair without QR code.
- (4) The examiner checked the reverse sides of the plates and added 10 points as a reward if the answer was correct. The examiner did not give any information to the examinee regarding whether the answer was correct or not.
- (5) Steps (2) to (4) were repeated 10 times, and the examiner calculated the correct answer rate.

Fig. 11 shows a scatter chart depicting the correct answer rates of the examinees. The horizontal axis shows the examinee numbers, the vertical axis shows the correct answer rate.

Fig. 11. Test results (Scatter Chart).

Fig. 12. Graph of frequency distribution.

wer rates of the examinees, and the red line indicates the average correct answer rate (33.3%). Fig. 12 shows a graph of frequency distribution versus correct answer rate. The peak occurs at 20%, which reduced the average rate as a whole. Accordingly, we concluded that distinguishing the presence or absence of QR code on a plate is visually difficult.

4.4 Obtaining photography of QR code and extracting information

To verify the satisfaction of requirement 3 (Information extraction) described in section 2.3, we photographed part of the plate that was baked with QR code using an IR camera in the same manner as in section 3.3, but we changed the power of the laser light on a three-point scale (300 mA, 400 mA, and 500 mA). Figs. 13 and 14 show the images before and after image processing with OpenCV⁽¹⁰⁾. We performed histogram adjustment, black/white inversion, and contour extraction. Afterwards, we extracted the information from each image with OpenCV and confirmed that the character string “Fuchi” was accurately extracted from each.

Fig. 13. Before image processing: Left: 300 mA, Center: 400 mA, Right: 500 mA.

Fig. 14. After image processing: Left: 300 mA, Center: 400 mA, Right: 500 mA.

5. Considerations

In this section, we discuss our proposed techniques from the points of view of requirement satisfaction and transfer paper manufacturing cost.

5.1 Requirement satisfaction

In this section, we discuss whether our techniques satisfy the four requirements listed in section 2.3.

(1) Requirement 1 (Effects on colors)

We printed the QR code on the transfer paper using an ink having a 1:1 ratio of glass phosphor weight to vehicle weight. However, as described in sections 4.1 and 4.2, the glass phosphor’s pale blue color was not distinguishable when we baked the QR code onto the white clay plate with transparent glaze. This result is the same as that previously found⁽³⁾, and it can be assumed that the amount of glass phosphor deposited in the 10.5 mm square was small. Accordingly, the same results should be seen in ceramics which have different clay, glaze, and paint colors. Thus, that the techniques described in sections 4.1 and 4.2 are effective and satisfy requirement 1.

(2) Requirement 2 (Difficulty of visibility)

As described in section 4.3, the average correct answer rate was 33.3% in our experiment with 30 examinees. This result indicates that the techniques described in section 3.2 worked as planned because the examinees could not easily distinguish the presence or absence of the QR code. Accordingly, we can conclude that the techniques described in 3.2 are effective and satisfy requirement 2.

(3) Requirement 3 (Information extraction)

As described in section 4.4, we obtained QR code images using an IR camera. We changed the power of laser light on a three-point scale. Moreover, the character strings were extracted correctly from each image using OpenCV. These results indicate that glass phosphor can emit near-IR light following optical excitation, an IR camera can capture the emitted IR light, and character strings can be extracted correctly from obtained images even if the laser power and amount of glass phosphor somewhat change. Accordingly, the techniques described in 3.3 are effective and satisfy requirement 3.

(4) Requirement 4 (Availability for the artifact-metrics)

Fig. 15 shows extracted images from each three plates with QR code used in the experiments in Section 4. As shown in these images, the light–dark differences between pixels are clearly evident (As a reference, histogram representation of each image is shown in Fig. 16.). These differences are

apparent because the size and thickness of glass phosphor particles are spontaneously and randomly determined during QR code baking so that differences are reflected. These differences are considered to constitute the characteristic information for artifact-metrics. Accordingly, our technique satisfies requirement 4.

Fig. 15. QR code images taken from each three plates with QR code.

Fig. 16. Histogram representation: Top (from the top of Fig. 15), Center (from the left of Fig. 15), Bottom (from the right of Fig. 15).

5.2 Manufacturing cost of transfer paper with QR code

We fabricated the transfer paper with QR code via four processes: (1) making 1 kg of glass phosphor, (2) making of ink (crushing of glass phosphor, fine granulation of glass phosphor powder, and mixing with vehicle), (3) platemaking for screen printing, and (4) printing. The total cost of producing 50 sheets of transfer paper with QR code in this experiment was about 3,668 USD, which was composed of the 2,771 USD cost for (1) and the cost of 898 USD each for (2)–(4). Simple calculations yield a price of about 74 USD for one piece of transfer paper. However, the abovementioned cost could be reduced, as transfer paper can be manufactured in practical situations. We estimate that the price of one piece of transfer paper with QR code is about several hundred dollars, as the market price of the printed transfer paper for ceramics is the same⁽¹¹⁾.

As a reference, we calculated the price of glass phosphor that is contained in one piece of transfer paper. Because we did not measure the amount of glass phosphor necessary to print the QR code evenly on one piece of transfer paper, we estimated the usage by considering a situation in which glass phosphor is printed evenly on a 10.5 mm square area of transfer paper. The thickness of this material is 10 μm . The weight of the 10.5 mm square area of 10- μm -thick glass phosphor was estimated to be 15.4×10^{-3} g, and the weight of the glass phosphor plate (50 mm square and 3 mm thick, as shown in Fig. 4) was 22 g. The price of glass phosphor contained in one piece of transfer paper was then estimated to be 4 cents. However, the price could be reduced if a massive amount of glass phosphor could be manufactured.

6. Conclusions

We proposed techniques to bake invisible QR code onto individual products during the manufacturing process and to extract information from products in a non-contact manner. The former is an application of the technique that bakes patterns onto ceramics by using transfer paper and screen printing. First, we printed QR code on the transfer paper by using an ink that contained transparent glass phosphor. Next, we set the resin layer with QR code between the clay and glaze layers. After firing, the transparent QR code was baked onto a plate. The latter process was performed so that the baked QR code could be imaged by using an IR camera and light source and the resulting image could be properly processed with OpenCV.

We confirmed that the pale blue color of the glass phosphor did not affect the glaze or the clay color after firing and that the QR code baked on the plate was difficult to detect visually. We also proved that the character strings could be extracted from photographic images of the baked QR code. Although up to 25 characters could be contained in the QR code, users could refer to product information via the Internet by using a secure web server and a short URL. We demonstrated that our techniques satisfied four requirements and that the manufacturing cost of the transfer paper was reasonable.

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