Technique for Embedding Information in Objects Produced with 3D Printer Using Near Infrared Fluorescent Dye

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***Abstract*—This paper provides a novel technique to embed information in objects fabricated with a 3D printer using a near infrared fluorescent dye. To embed information inside an object, regions containing a small amount of fluorescent dye are formed inside the object as it is fabricated, and these regions form a pattern that expresses certain information. When this object is irradiated with near-infrared rays, they pass through the resin but are partly absorbed by the fluorescent dyes, and the fluorescent dyes emit near-infrared fluorescence. Therefore, by using a near-infrared camera, the internal pattern can be captured as a high-contrast image and the embedded information can be nondestructively read out. We conducted experiments to confirm the principle of the technique and demonstrate its feasibility. A sample was prepared using a two head fused deposition modeling-type 3D printer. On the basis of the experimental results, it was determined that a bright and high-contrast image could be taken if the pattern was formed at a depth of 1 mm or less from the surface, demonstrating the feasibility of this technique.**

Keywords-3D printer; information hiding; near infrared light; fluorescent dye.

I. INTRODUCTION

In recent years, 3D printers have spread rapidly because they have become smaller and cheaper. If consumers have a 3D printer in their own home or office, they can easily obtain a product that they want just by buying the 3D model data through the Internet and print it. Therefore, it is expected that 3D printers may bring a revolution in the manufacturing industry and logistics [1]-[3].

Moreover, 3D printers use a process called additive manufacturing in which thin layers are formed one by one to form an object. This makes it possible to form a fine structure inside the object. Using this process, we have been studying techniques that can embed information inside an object by forming fine patterns that express information in the object while it is fabricated. We have also been studying techniques that can read out such information nondestructively from the outside.

The embedding of information inside 3D printed objects will enable extra value to be added to 3D printed objects, expanding their applications. For example, we can embed information that usually comes with newly purchased products (e.g., user manuals) into the objects. We can also embed watermarks to protect the copyright of the original 3D model data. Although this is similar to conventional watermarking for digital content [4], the final product is not digital data but a real physical object. Therefore, a watermark needs to be embedded into it. Moreover, it will be also possible to use the object as a “thing” of Internet of Things (IoT) connecting the Internet.

To develop a nondestructive information readout technology, we examined a method using thermography [5] [6] and a near infrared camera [7] [8]. We formed small cavities inside an object as fine patterns at shallow depths from the surface using thermography. Since a cavity has a very low thermal conductivity, the temperature of the surface above them becomes higher than other areas when the surface is heated, therefore, we can know where cavities are in the object and read out the information.

We formed the fine patterns using a resin that has a high reflectivity or high absorption rate for infrared light when using an infrared camera. We can obtain the pattern in this case too because most resin materials transmit infrared rays.

As related work, the technique of embedding information inside 3D printed objects using a thin plate with a cutout pattern has been studied in recent years. Willis and Wilson [9] first created some product parts, one of which had a visible pattern, and then assembled these parts into one product so that the patterned part was inside it. They read out the patterned information inside by using terahertz wavelength light. However, in practical terms, it was too complicated to apply it to common 3D printing. In contrast, the fine patterns in our technique are integrally formed using the body-utilizing additive manufacturing process of 3D printers, which eliminates any additional processes.

In this paper, we propose a new technique for forming an inside pattern containing a small amount of fluorescent dye. In Section 2, we describe the principle of the proposed technique. Since the dye emits fluorescence, it is expected that high-luminance, high-contrast pattern image can be captured. This paper also describes the experiment we conducted to confirm the feasibility of this technique in Sections 3 and 4. We conclude this paper in Section 5.

 ISBN: 978-1-61208-697-2

II. INFORMATION EMBEDDING USING FLUORESCENT DYE

Figure 1 shows the basic principle of the proposed technique. This technique assumes that the resin is used as an object material. Pattern regions inside the object are formed using the same resin as that of the other regions, but they contain a small amount fluorescent dye. Since resin has high transmittance for near infrared, when the object is irradiated with near-infrared rays from the outside, the rays reach the internal fluorescent dyes. The light source irradiates light with wavelength λ_E, which excites the fluorescent dye. The fluorescent dye is excited and emits fluorescence. Therefore, a bright image of the patterns inside the resin object can be captured.

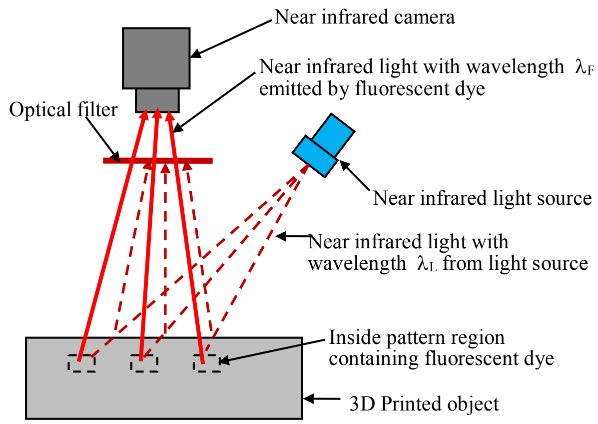

Figure 1. Basic concept of proposed technique

Since wavelength λ_F of the dye's fluorescence differs from wavelength λ_E of the irradiated light, only light the fluorescent dye emits enters the camera, using an optical filter that blocks the light from the light source. In our previous studies where near infrared rays were used, reflective light from the object surface also entered the camera as noise. This decreased readability of the embedded information. In contrast, since the technique in this study can block such reflective light from the surface, it is expected that a low noise image of the pattern can be obtained, enhancing the readability.

Using the same color of resins for the body and internal patterns, the patterns cannot be seen from the outside even if they are formed in a very shallow position from the surface. This is because the amount of the fluorescent dye contained in the resin is very small, and this hardly changes the color of the resin. This is important for applications requiring embedded information to remain hidden.

III. EXPERIMENTS

A. Sample preparation

Figure 2 shows the designed layout of the sample. In many practical cases of fabricating an object with a resin material, its inside is hollow as shown Figure 2, requiring only thin walls to maintain the strength of its body (the walls are omitted in this figure). Therefore, even in this study, samples whose insides are hollow were prepared. As shown in the figure, the internal patterns contact the inner wall of the outer shell. The sizes of the internal pattern and spaces between them were changed as experimental parameters as listed in Table 1. The thickness of the outer shell of the main body was also changed from 0.5 to 2 mm as an experimental parameter.

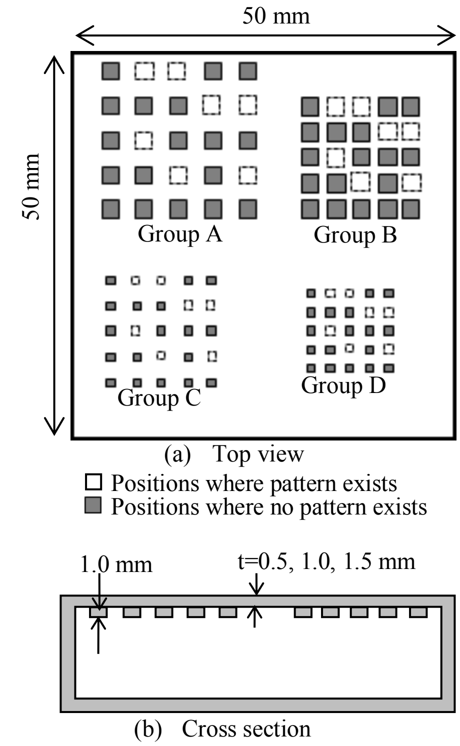

Figure 2. Layout of sample

TABLE 1 LAYOUT PARAMETERS OF PATTERNS IN SAMPLE

	Size	Space
Group A	2	2
Group B	2	1
Group C	1	2
Group D	1	1

(mm)

Figure 3 shows a photo of the 3D printer used to fabricate the samples. We used a fused deposition modeling (FDM)-type dual-nozzle 3D printer, Mutoh Value3D MagiX 2200D, to use two materials for one single object.

The body structure was fabricated using pure Acrylonitrile Butadiene Styrene (ABS) resin, and the inside patterns were formed using the same color of ABS resin as that for body, however, it contained a small amount of florescent dye (less than 1%). Figure 4 shows an example of the samples whose outer shell thickness t is 0.5 mm, in which the internal patterns cannot seen from the outside at all.

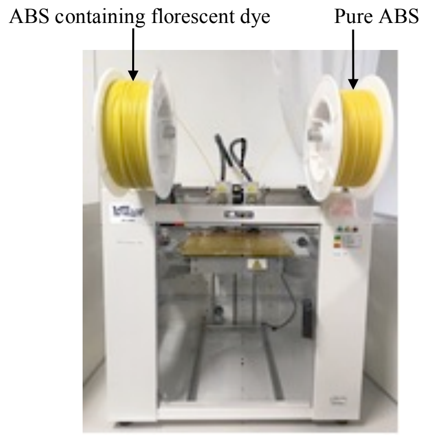

Figure 3. 3D printer used in experiment to fabricate samples

Figure 4. Example of samples.

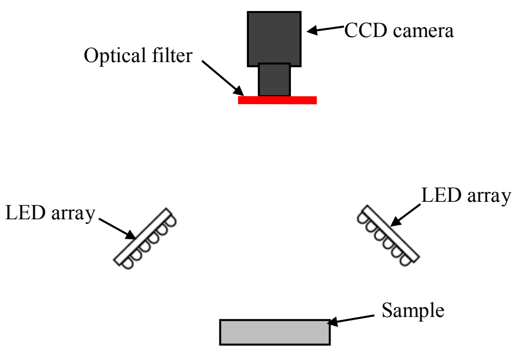

Figure 5. Layout of equipment to capture near infrared images

B. Capture of near infrared image

Figure 5 illustrates the layout of the equipment used to capture a near infrared image. We used two sets of LED arrays as near infrared light sources. A CCD camera with 2048 x 1088 pixels, which was sensitive to light with wavelengths up to 1100 nm, was set at the same side as above the sample, between the LED arrays. An optical filter was placed in front of the camera.

IV. RESULTS AND DISCUSSION

Figure 6 shows the images captured with CCD camera. For all groups in the sample with t=0.5 mm, we can clearly determine the presence or absence of internal patterns at predetermined positions. For the sample with t=1.0 mm, although the image is blurred, it can barely be determined whether there is a pattern at a predetermined position. However, we cannot determine the presence or absence of any patterns in any group of the sample with t=1.5 mm due to the large degree of blur in the image. From this result, it can be seen that binary information can be read out if the distance from the object surface to the pattern is within 1 mm and the pattern size and the interval are 1 mm or more.

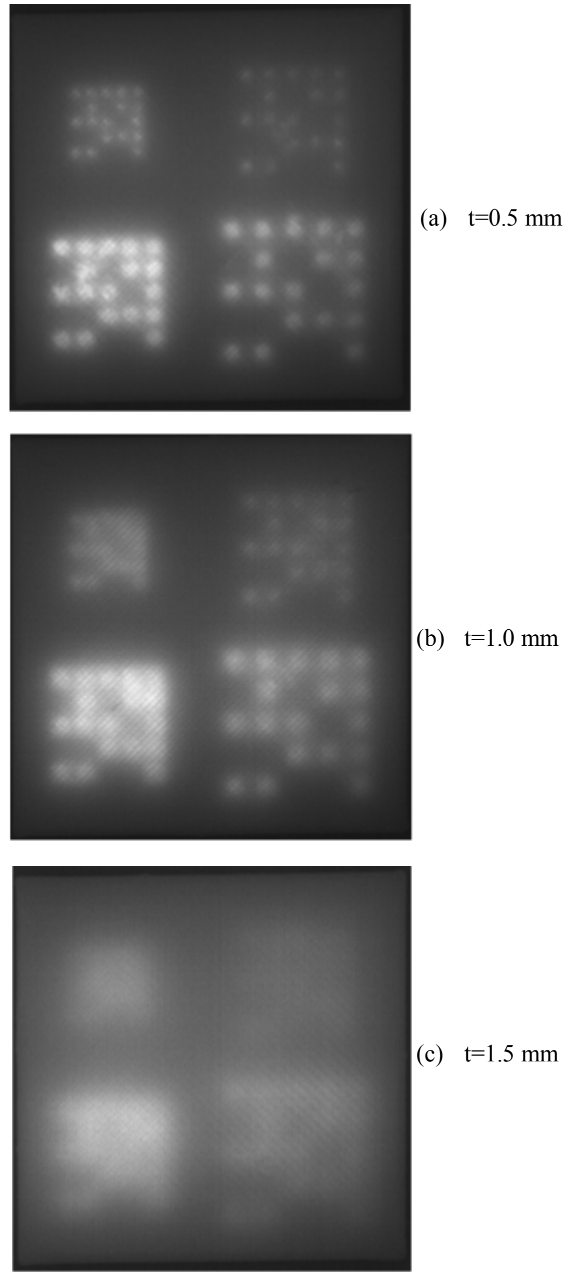

Figure 6. Captured images with CCD camera

The captured images shown in Figure 6 have low noise and high contrast. These make it easy to distinguish whether

 ISBN: 978-1-61208-697-2

or not a pattern exists. This demonstrates that the proposed technique using a fluorescent dye has the effect we expected.

The blur in the image occurs because the near infrared rays are scattered as it passes through the ABS resin. Therefore, as the path becomes shorter, the blurring becomes less, that is, in order to reduce blurring, it is necessary to shorten the distance from the surface of the object to the region containing the fluorescent dye. Since thinning the outer shell decreases the strength of the object's body, a method of forming a region containing a fluorescent dye in a part of the outer shell without reducing the thickness of the outer shell can be a candidate countermeasure. Verification of the effectiveness of this idea is a future task.

V. CONCLUSION

We have studied a technique of forming an internal pattern region in a 3D printed object with ABS resin containing a very small account of fluorescent dye to enhance contrast and decrease noise in images of the patterns and to enhance readability of the embedded information the patterns express.

From the experiments we conducted, we clarified that bright and low-noise images of the internal pattern could be captured as expected and it enhanced readability for embedded binary information.

In future work, we will decrease image blur of internal patterns by shorten the distance from the object surface to the internal pattern to enable higher density information embedding.

ACKNOWLEDGMENT

This research was supported by Japan Society for the Promotion of Science Grant-in-Aid for Scientific Research 15H02707. Moreover, we would like to thank DIC Corporation for providing the fluorescent dye contained in the ABS resin in this research.

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