

Embedding Information in 3D Printed Objects Using Double Layered near Infrared Fluorescent Dye

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Abstract—This paper provides a novel technique to embed high-density information in objects fabricated with a 3D printer using a near infrared fluorescent dye. Regions containing a small amount of fluorescent dye are formed inside the object as it is fabricated to embed information inside an object, 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 dye, and it emits 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. This paper presents a technique of forming internal patterns at two different depths to double the amount of embedded information. We can know the depth of the patterns from the image because the profile of the brightness of the captured image of the patterns depends on its depth. Using these profiles enables doubling the amount of embedded information. Experiments we conducted demonstrate the feasibility of this technique.

Index Terms—3D printer, information hiding, near infrared light, fluorescent dye.

I. INTRODUCTION

3D printers have been attracting attention as a new method of manufacturing. This is because we can easily obtain a product that we want just by inputting the model data into a 3D printer. Thus, 3D printers are expected to revolutionize manufacturing in the future [1]-[3].

3D printers use a process called additive manufacturing [4] in which thin layers are formed one by one to form an object. This enables forming any structure inside the object during fabrication. We have studied techniques that can embed information inside an object formed of resin using this process by forming fine patterns that express information in the object [5]-[9].

In addition to embedding information, we have also studied techniques that can read out embedded information nondestructively from the outside using a thermography and

a near infrared camera.

We have also studied a technique that forms patterns containing a small amount of fluorescent dye [10]. These dyes emit near-infrared fluorescence; therefore, the internal patterns can be captured as a high-contrast image using a near-infrared camera. This enhances the readability of the embedded information.

Related work includes a technique of embedding information inside 3D printed objects using a thin plate with a cutout pattern. Willis and Wilson [11] first created 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 using terahertz wavelength light. However, in practical terms, applying it to common 3D printing was too hard. 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.

This paper describes a technique that can double the amount of information embedded. It embeds patterns containing fluorescent dye at two different depths to achieve double the amount of embedded information. Experiments we conducted demonstrate the feasibility of this technique.

II. INFORMATION EMBEDDING USING FLUORESCENT AND DOUBLE DEPTHS EMBEDDING

A. Information Embedding Using Fluorescent Dye

Fig. 1 shows the basic principle of the technique using fluorescent dye. It assumes that the resin is used as an object material. The dotted rectangles in Fig. 1 indicate the inside pattern region. Although many ways are possible to express information using these patterns, we expressed binary information by the existence or non-existence of the patterns at a pre-determined position in the object.

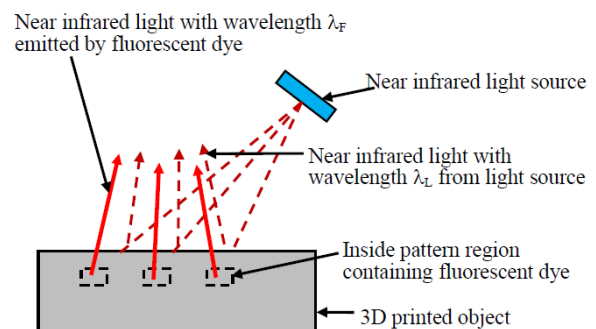


Fig. 1 Basic concept of our technique.

The pattern regions are formed using the same resin as that

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of the other regions, but they contain a small amount of fluorescent dye. The rays reach the internal fluorescent dyes when the object is irradiated with near-infrared rays from the outside because resin has high transmittance for near infrared. The light source irradiates light with wavelength λ_E , which excites the fluorescent dye. The dye is excited and emits fluorescence with wavelength λ_F , which differs from λ_E . Because fluorescent dye emits the light, a bright image of the patterns inside the resin object can be captured.

Because 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; therefore, a low noise image of the inside patterns can be obtained.

B. Dual Depth Embedding

Fig. 2 shows the basic configuration of dual depth embedding. The inside patterns are formed at two different depths. We can express 2-bit binary information using this arrangement. For example, we can assign 11 when patterns exist at both depths (Fig. 2A), 10 when a pattern exists at only low depth (Fig. 2B), 01 when it is at only high depth (Fig. 2C), and 00 when no pattern exists (Fig. 2D). In the previous method, only one bit could be embedded at one position, but this method enables embedding two bits and the amount of information that can be embedded is double.

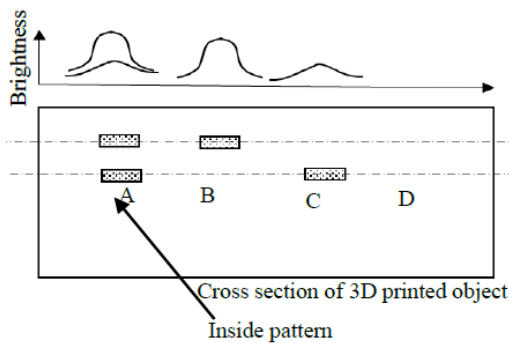


Fig. 2. Basic configuration of dual depth embedding.

Near-infrared rays transmit through the resin but are scattered during transmission. This scattering increases as the passing distance increases. Therefore, when the near infrared image of the internal pattern is captured from the outside, the image blurs. In addition, the blurring becomes more pronounced for deep image patterns. The difference in the brightness distribution of the captured image of the patterns at positions B and C in Fig. 2 shows this state. When patterns are at two depths, the brightness distribution is the sum of them, as shown in Fig. 2, for position A. Therefore, the brightness distribution of the captured image differs in four cases, and we can recognize which of the four numbers between 00 and 11 is which from the brightness distribution.

III. EXPERIMENTS

A. Sample Preparation

Fig. 3 shows the designed layout of the sample. Four types of arrangements of patterns at two depths were formed in equal numbers for each row. The pattern size was 2×2 mm,

and the thickness was 1 mm. The depth of the upper pattern from the surface was 0.3 mm, and that of the bottom pattern was 2 mm.

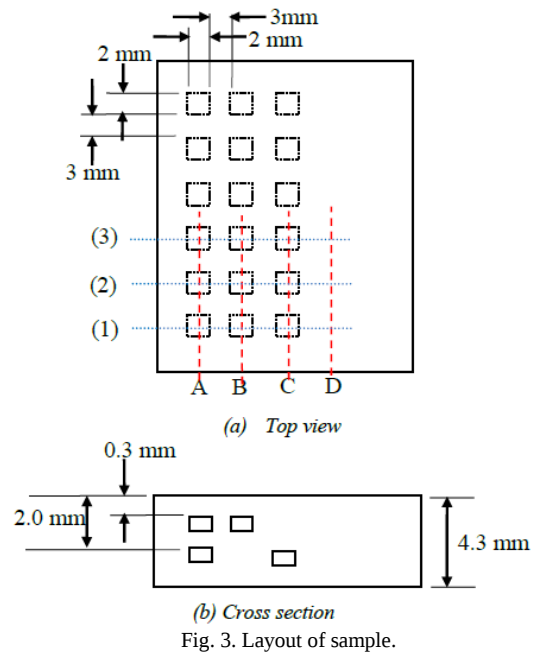


Fig. 3. Layout of sample.



Fig. 4. Filaments made of these ABS resins. The filament on the right contains dye, one on the left is pure one.

We used a fused deposition modeling (FDM) 3D printer, Mutoh Value3D MagiX 2200D, to fabricate the samples. It has two nozzles so that two materials can be used for a single object.



Fig. 5. Example of samples.

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 the body; however, it contained a small amount of fluorescent dye (less than 1%). Fig. 4 shows filaments made of these ABS resins.

Fig. 5 shows an example of the samples. These two filaments differ slightly in color because one contains very little dye, but the internal pattern is not perceptible to the naked eye in the sample in Fig. 5.

B. Capture of Near Infrared Image

Fig. 6 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 2048×1088 pixels, which was sensitive to light with wavelengths up to 1100 nm, was set at the same side as the aforementioned sample between the LED arrays. An optical filter was placed in front of the camera.

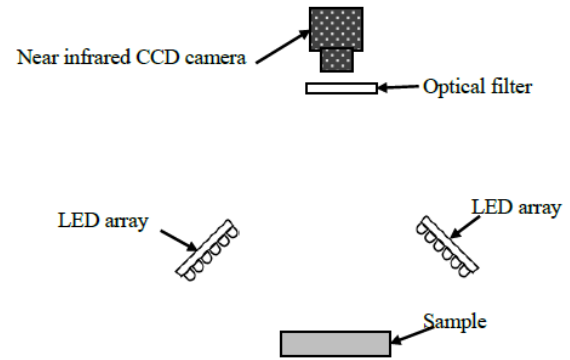


Fig. 6. Layout of equipment to capture near infrared images.

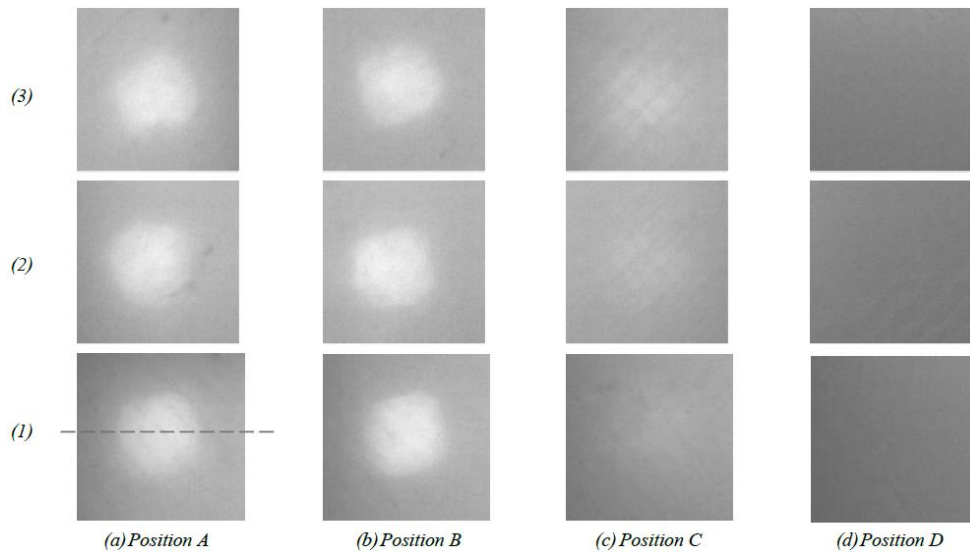


Fig. 7. Captured images with CCD camera.

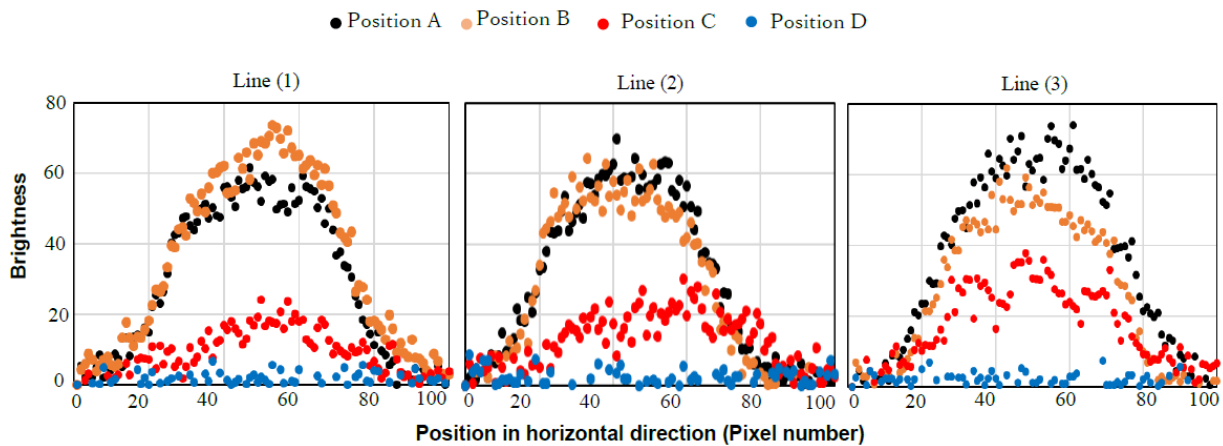


Fig. 8. Brightness distribution.

IV. RESULTS AND DISCUSSION

Fig. 7 shows the example images of the sample captured with a CCD camera. In Fig. 7, the vertical columns and the horizontal rows correspond to the columns A to D and the rows (1) to (3) shown in Fig. 3(b). Although the brightness of the images differs depending on the row due to the shading of the illumination, it is seen from Fig. 7 that the brightness distributions of the inside pattern at the position of B, C, and D clearly differ. Fig. 8 shows the brightness distributions of images in the first row shown in Fig. 7 along the horizontal line passing through the center, an example of which is indicated by dotted line in Fig. 7(a)(1). The brightness

distributions in Fig. 8 is shading corrected, and the bias value is subtracted so that the brightness in the periphery becomes zero. It can also be seen from Fig. 8 that the brightness distributions of the images at positions B, C and D are clearly different. Moreover, in comparing the brightness distribution of the image at positions B and C, we can see clearly that the deeper the region containing the fluorescent dye, the more blurred the image of the region.

However, the difference between those at the positions A and B are slight. Determining which is which may be difficult. The cause of this is the brightness of the deeper pattern is very low. If the deeper pattern is made a little shallower, the

difference may become larger.

However, as shown an example in Fig. 8, the differences appeared in their histograms. That is, the histogram of the image at position A has a wider main peak than that at position B. This spread is due to the deeper pattern. Therefore, four states can be distinguished from the luminance distribution and histogram.

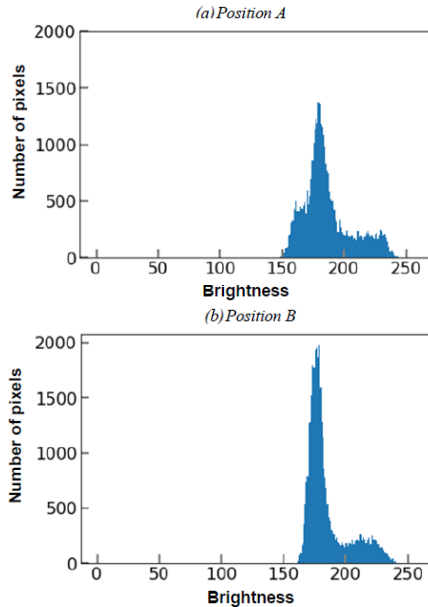


Fig. 9. Histogram of the captured images.

V. CONCLUSION

We studied a technique of forming internal patterns in a 3D printed object with ABS resin containing a very small amount of fluorescent dye to enhance contrast and decrease noise in images of the pattern and to enhance the readability of the embedded information the pattern expresses. In particular, we studied a method to double the amount of embedded information by forming a pattern at two depths. The experiments showed that a pattern can exist or not exist at two different depths using the fact that the blurring of the image of the pattern differs depending on its depth. That is, this method was shown to be able to double the amount of embedded information.

In future work, we will apply pattern recognition such as deep learning to distinguish four states to see how accurate embedded information can be read out.

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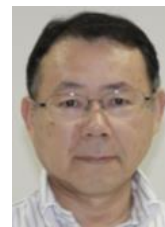


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