Embedding Information in 3D Printed Objects with Curved Surfaces Using Near Infrared Fluorescent Dye

*Piyarat Silapasuphakornwong, **Hideyuki Torii, **Kazutake Uehira
Human Media Research Center
Kanagawa Institute of Technology
Atsugi, Japan
*e-mail: silpiyarat@gmail.com,
**email: {torii, uehira}@nw.kanagawa-it.ac.jp

Siravich Chandenduang
Department of Mathematic & Computer Science
Chulalongkorn University
Bangkok, Thailand
e-mail: Siravich93@gmail.com

***Abstract*—This paper presents a technique to embed barcodes in the curved surfaces of objects fabricated with a 3D printer. The objects are fabricated using resin material, and the barcodes patterns inside an object are formed using the same resin material as other regions but containing a small amount of fluorescent dye. When these objects are irradiated with near-infrared rays, fluorescent dyes are excited, and they emit near-infrared fluorescence. Therefore, the internal barcode patterns can be captured as high-contrast images using a near-infrared camera, and the information expressed by the barcodes inside the objects can be nondestructively read out. We conducted experiments to demonstrate that this technique can also be applied to objects with curved surfaces. A sample was prepared using a 3D printer with two-head fused deposition modeling. The experimental results show that we can hide a barcode inside an object so that no one can see it from the outside and that we can decode all barcodes correctly with 100% accuracy.**

Keywords-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 consumers can easily obtain a product that they want just by buying the model data through the Internet and print it if they have a 3D printer in their own home or office. 3D printers have been reduced in price and miniaturized. Notice that we could not see the barcodes from outside all of the sample. Thus, the barcodes were hidden completely. Thus, 3D printers are expected to revolutionize distribution and manufacturing in the future [1] – [3].

3D printers use a unique process called additive manufacturing in which thin layers are formed one by one to create an object [4]. This enables forming any structure inside the object. We have used this feature in our study on the techniques of embedding information inside a 3D printed object, and we were able to form fine patterns inside the object to express information [5] – [9].

The embedding of information inside 3D printed objects will enable adding extra value to these objects. For example, we can embed information that usually comes with newly purchased products into them. Moreover, it will be possible to use them as “things” of the Internet of Things (IoT) in connecting to the Internet.

We have studied some methods of forming fine patterns inside a 3D printed object that used a Fused Deposition Modeling (FDM) 3D printer with resin as a material. One of them is a method that forms internal patterns using resin containing a small amount of fluorescent dye [10]. Fluorescent dye emits fluorescence when near-infrared rays are irradiated; therefore, the internal pattern can be captured as a high-contrast image using a near-infrared camera. This enhances the readability of the embedded information.

So far, we have demonstrated the feasibility of this technique and also the possibility of high density information embedding by forming inside patterns at double depth [11]. This study was conducted using flat surface sample objects because they were intended to determine the feasibility and because flat surfaces made the experiment easy. However, we have to demonstrate that this technique can also be applied to many general objects for practical use because such objects usually have curved surfaces. This paper describes our experiments using objects with curved surfaces and the results we obtained.

The rest of the paper is organized as follows: the principle of basic embedding fluorescent dye into a fabricate object and its readout method are described in Section II. Then, we show the feasibility and method how to embedding barcodes under the curve surface and evaluation in Section III. Next, Section IV is the results and discussions, followed by the conclusion in Section V, respectively.

II. INFORMATION EMBEDDING USING FLUORESCENT DYE

The technique of using fluorescent dye for internal patterns is illustrated by Figure 1. 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 other regions, but they contain a small amount of fluorescent dye. Because resin has high transmittance for near infrared, the rays reach the internal fluorescent dyes when the object is irradiated with near-infrared rays from the outside. The light source irradiates light with wavelength λ_E, which excites the fluorescent dye. The fluorescent dye is then excited and emits fluorescence. Therefore, a bright image of the patterns inside the resin object can be captured.

 ISBN: 978-1-61208-772-6

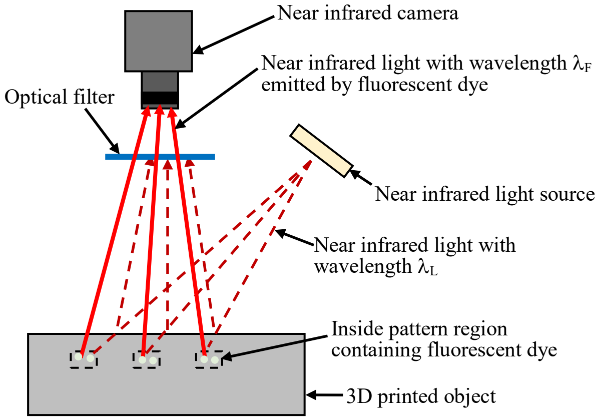


Figure 1. Basic concept of proposed technique [10]

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 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 the readability of the embedded information. In contrast, because the technique in this study can block such reflective light from the surface, a low noise image of the pattern should be obtainable, enhancing readability.

The patterns cannot be seen with the naked eye from the outside using the same color of resins for the body and internal patterns 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. This is important for applications requiring embedded information to remain hidden.

III. Experiments

In this paper, we focus on applying this technique to the curved objects in order to confirm the feasibility to apply in practical general 3D objects. Most general 3D objects have curved surfaces. The difference in the incidence and reflection of light on the curved surface is irregular. It may have some effects on the appearance in captured images, such as brightness and contrast. Therefore, it could affect the readability of the read-out process in the end. Hence, we set up experiments to find the appropriate factors in our technique concerning when our technique should be applied in practical situations.

A. *Sample preparation*

We prepared samples and evaluated the results using the workflow shown in Figure 2. The 3D models were built from a CAD program. With this step, barcodes containing information on the word “Hi” were embedded and hidden inside the 3D models, as shown in Figure 3. We varied the depth of embedding the barcodes at 0.5 and 1.0 mm, and we placed them in 3D models such as a half sphere and a half cylinder to compare the effect of the curved surfaces on the samples. The space between each line of the barcodes was at

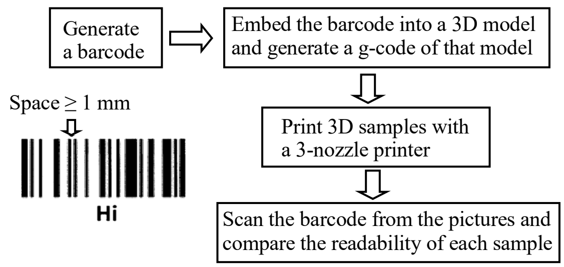


Figure 2. Workflow of experiment

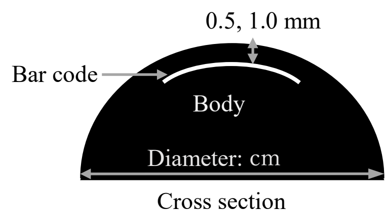


Figure 3. Cross section of our sample used in the experiment

TABLE I. DESIGNED SAMPLES IN EXPERIMENTS

3D Model	Diameter (cm)	Depth of barcode from surface (mm)
Sphere	8	0.5
		1.0
Cylinder	4.5	0.5
		1.0

least 1 mm, and the size of each line was 1 mm. The design of the samples is shown in Table I. Then, a sample file was generated in the g-code file for slicing. After that, the samples were created using a 3D printer with two nozzles, one nozzle being a normal ABS and the other being an ABS-fluorescent dye mixed filament, as shown in Figure 4 (left). After printing, we captured images of samples using a near infrared camera with a specific optical filter. The barcodes, which were embedded inside the objects, would then appear. Finally, we scanned the barcodes of the pictures we took and compared the readability of each object.

B. *Capture of near infrared images*

We used a near infrared CCD camera with a specific optical filter to capture the images of the hidden barcodes inside the samples. The resolution of the images was 2048 x 1088 pixels. The layout of the samples with instruments is shown in Figure 4 (right). To read out the data embedded in the objects, we used a QR & barcode scanner application available on Android and a QR-scanner application available on iOS for decoding the barcodes. However, some images could not be read out directly from the capturing process. To solve this problem, we enhanced them by adjusting their sharpness using the sharpness enhancement mode provided by Microsoft PowerPoint. Then, we repeated the scanning

 ISBN: 978-1-61208-772-6

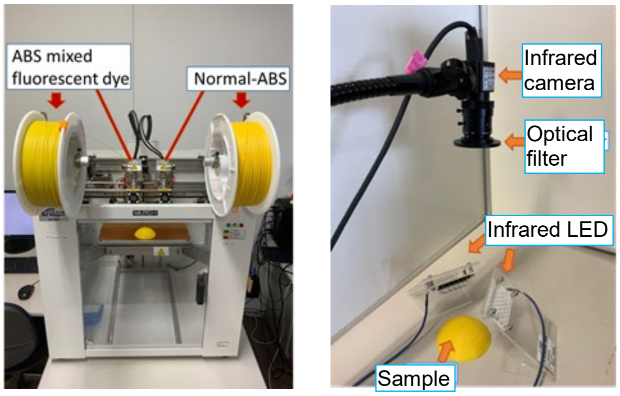


Figure 4. Experiment setup: (left) a two-nozzle printer, (right) Layout of instruments for evaluation

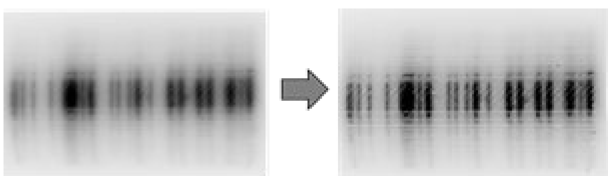


Figure 5. Enhancement process: (left) before enhancement, (right) after enhancement by adjusting sharpness

step. The enhancement process is shown in Figure 5.

We tried to read out the barcodes using the automatic barcode scanner application ten times and reported the % accuracy, both in before and after enhancement images, as determined with the following equation. The accuracy measures how it is easy to access to readout barcodes—change to word or some understandable information.

$$\%\ \text{accuracy} = \frac{times\ of\ readout\ success}{Total\ numbers\ of\ readout} \quad (1)$$

IV. Results and Discussion

Table II shows the 3D models of the half spheres and cylinders after printing them with the bar code depth varied at 0.5 and 1.0 mm below the surface and the readout results, respectively. Notice that we could not see the barcodes from outside all of the samples. Thus, the barcodes were hidden completely.

When the depth of 0.5 mm was used in both the half sphere and cylinder surfaces, the barcodes could be read out within a second (almost immediately), and no sharpness enhancement was needed. We could decode from the captured images directly.

Nevertheless, for an embedding depth of 1.0 mm, both the half sphere and cylinder surfaces could be read out using the same application, but more time was needed, along with an ideal position to read the barcodes. Thus, the sharpness needed to be improved. After sharpness was enhanced, they could be read out within a second (almost immediately). Also, the results of the embedding depth of 0.5 mm were the same.

The samples of the embedding depth barcode of 1.0 mm could not be read out directly because of the irregularity of incident and reflect lighting on the curved surfaces. The curves of the surfaces made the distance different between the barcodes to the light and camera in each area. The center of the curves was the highest. Hence, we could capture the images very clearly because they were near the camera and in the point of focus. However, the barcodes at the curved rims were the farthest from the camera, making the capture images from this area very blurry and unreadable because they were out of focus.

However, after the enhancing process, the barcodes could be read out effectively. We tried to enhance the sharpness of images in both the 0.5 and 1.0 mm samples. The results were that they could be read smoothly. That let us know that the sharpness was an important factor for our technique to ensure the readability of the hidden barcodes inside 3D models. Hence, we will utilize our method to enhance the sharpness of captured barcode images for effective readouts when our technique will be applied in practical applications for embedding information in general 3D models, the main target for our study. That will make the information on decoding more accurate and make the readability more efficient.

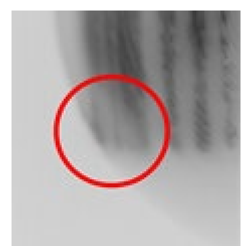


Figure 6. Problem of barcode at the rim of the curved surface model

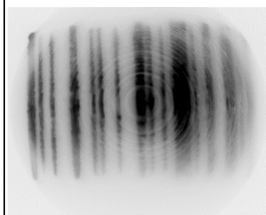
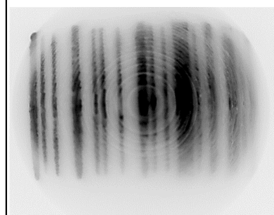
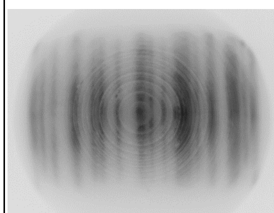
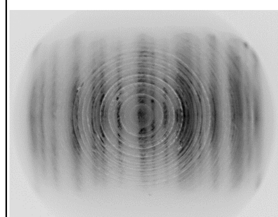
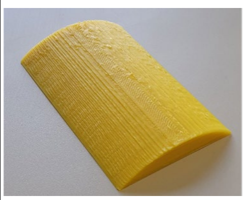
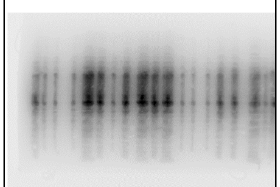
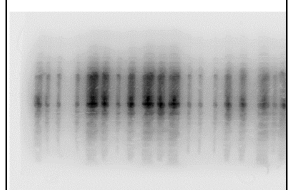
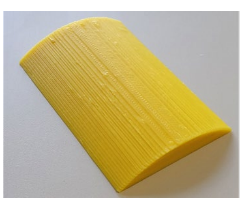
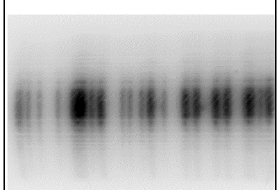
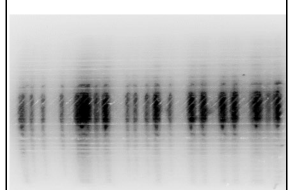
Moreover, we will endeavor to embed QR codes instead of barcodes in future work because they can increase the amount of embedded information, though they will increase the difficulty of readouts. With the principle of reading out the barcodes, the patterns just clarify only a tab where the length is greater than the width at a propagation of 2:1. This will make the barcodes much easier to decode than QR codes. For QR codes, all of their positions have to be completely clear. The rim of the curved surfaces mainly cause a problem with reading because the images are blurry and the codes distort (caused by the shape model and printing), as shown in Figure 6. Thus, we have to determine feasibility in future work for this reason.

V. Conclusion

We proposed a technique of non-destructively reading out information embedded inside curved objects using near-infrared light. We determined the feasibility of applying our technique to general non-flat models by creating 3D curved samples, such as spheres and cylinders, by varying the depth

Copyright (c) IARIA, 2020. ISBN: 978-1-61208-772-6

TABLE II. RESULTS OF EXPERIMENTS

Model: Embedded Depth (mm)	Real Printed Object	Captured Infrared Image	Readability	After Enhancing Image	Readability
Sphere: 0.5 mm			√ (Fast) 100%		√ (Immediate) 100%
Sphere: 1.0 mm			X (Only from an ideal position & with slow readout) 50%		√ (Fast) 100%
Cylinder: 0.5 mm			√ (Fast) 100%		√ (Immediate) 100%
Cylinder: 1.0 mm			X (Only from an ideal position & with slow readout) 50%		√ (Fast) 100%

below the surface of barcodes between 0.5 and 1.0 mm, and by comparing the same model with different barcode depths. The results showed the feasibility of hiding the barcodes inside the objects so that no one can see even part of them from the outside and the feasibility of decoding all the barcodes correctly with 100% accuracy. The best barcode depth for embedding was found to be 0.5 mm. Although, at the depth of 1.0 mm, we could not read out the barcodes directly from the captured images, enhancing the process helped with reading out the barcodes correctly. We found that sharpness was an importance factor of readability in our technique, for both 0.5 and 1.0 mm surface embedded thickness. We can choose to embed information at a depth of 0.5 mm from the surface in 3D printed objects. At this depth, we do not need any sharpness enhancement to read out information, ensuring the best conditions, convenience, and efficiency for use in practical applications. The target of our study is to apply our proposed method to cover all cases of real-world printed objects in the future. Thus, we will also try to embed QR codes instead of barcodes in both flat, curved, and general surfaces in order to increase the amount of information embedding effectively.

ACKNOWLEDGMENT

We would like to thank DIC Corporation for providing the fluorescent dye contained in the ABS resin in this research.

REFERENCES

[1] B. Berman, “3-D printing: The new industrial revolution,” Business horizons, vol. 55, no. 2, pp. 155–162, March–April 2012.

[2] B. Garrett, “3D printing: New economic paradigms and strategic shifts,” Global Policy, vol. 5, no. 1, pp. 70–75, February 2014.

[3] C. Weller, R. Kleer, and F. T. Piller, “Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited,” International Journal of Production Economics, vol. 164, pp. 43–56, June 2015.

[4] F. Hartung and M. Kutter, “Multimedia watermarking techniques” Proc IEEE, Vol. 87, No. 7, pp. 1079–1107, 1999.

[5] M. Suzuki, P. Silapasuphakornwong, K. Uehira, H. Unno, and Y. Takashima, “Copyright protection for 3D printing by embedding information inside real fabricated objects,” International Conference on Computer Vision Theory and Applications, pp. 180–185, March 2015.

[6] M. Suzuki, et al., “Embedding Information into Objects Fabricated With 3-D Printers by Forming Fine Cavities inside Them”, Proceedings of IS&T International symposium on Electronic Imaging, Vol. 2017, No. 41, pp. 6–9, 2017 .

[7] P. Silapasuphakornwong, et al., “Nondestructive readout of copyright information embedded in objects fabricated with 3-D printers”, The 14th International Workshop on Digital-forensics and Watermarking, Revised Selected Papers, pp. 232–238, 2016.

[8] K. Uehira, et al., “Copyright Protection for 3D Printing by Embedding Information Inside 3D-Printed Objects”, The 15th International Workshop on Digital-forensics and Watermarking Revised Selected Papers, pp. 370–378, 2017.

[9] K. D. D. Willis and A. D. Wilson, “Infrastructs: Fabricating Information Inside Physical Objects for Imaging in the Terahertz Region”, ACM Transactions on Graphics, Vol. 32, No. 4, pp. 138-1–138-10, July 2013.

[10] P. Silapasuphakornwong, M. Suzuki, H. Torii, and K. Uehira, “Technique for embedding information in objects produced with 3D printer using near infrared fluorescent dye”, Proceedings of MMEDIA, pp. 55-58, 2019.

[11] H. Kasuga, P. Silapasuphakornwong, H. Torii, M. Suzuki, and K. Uehira, “Technique to Embed Information in 3D Printed Objects Using Near Infrared Fluorescent Dye”, Proceedings of IECIE, 2019.

 ISBN: 978-1-61208-772-6