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Embedding Information into Objects Fabricated With 3-D Printers by Forming Fine Cavities inside Them

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Abstract

We evaluated our previously proposed technique of protecting the copyrights of digital data for 3-D printing. This technique embeds copyright information into not only digital data but also fabricated objects and enables the information to be read to reveal possible copyright violations. The insides of fabricated objects are constructed with fine cavities to embed information into them. In this study, the readability of embedded information relating to the structure parameters of the fine cavities inside fabricated objects was examined to clarify the conditions in which this technique can be applied. The top-view sizes of the cavities, the top-view spaces between cavities, the depths of the cavities themselves, and the depths of the cavities from the surfaces of the objects were changed as experimental parameters. Experimental results clarified the conditions for forming cavities inside the fabricated objects and showed that a sufficient amount of information for copyright (i.e., hundreds of bits) could be embedded if a fabricated object was several centimeters in size.

Introduction

Three-dimensional (3-D) printers have become popular with consumers. People who have 3-D printers can easily fabricate products by simply obtaining the digital data for 3-D printing. Hence, many people believe that 3-D printers will change the ways in which manufacturing and physical distribution will be carried out in the near future [1] [2].

However, such benefits of 3-D printers mean that anyone can easily manufacture bootleg products if he or she abuses digital data for 3-D printing. Such copyright violations will obviously cause serious economic damage. Thus, techniques to protect the copyrights of digital data for 3-D printing are essential for the healthy development of markets for 3-D printers.

Although techniques to prevent illegal copying or illegal printing are of course important to protect the copyrights of digital data for 3-D printing [3]–[6], techniques to divulge such violations are additionally crucial in cases in which these violations occur. Digital watermarking is common in all kinds of digital data for disclosing copyright violations; however, conventional techniques can only embed watermarks into digital data but not into real objects fabricated with 3-D printers. Copyright information needs to be embedded into fabricated objects so that the information can be read to reveal any violations. For example, when companies that are not allowed to use digital data held by the copyright holder are selling illegally fabricated objects, the copyright holder can expose the companies by detecting the copyright information embedded into the sold objects and assert his or her just rights. Thus, techniques to reveal copyright violations, i.e., embedding readable copyright information into fabricated objects are essential for protecting the copyrights of digital data for 3-D printing.

We previously proposed a technique to embed readable copyright information into fabricated objects and demonstrated its feasibility [7] [8]. With this technique, the inside of objects is constructed with fine domains, which have different physical characteristics from the objects' main bodies surrounding them, to embed the information. These fine domains are detected using nondestructive inspections, such as X-ray photography or thermography, to reveal the embedded information. Our previous studies demonstrated that information embedded with fine cavities inside objects can be read. Thus, information can feasibly be embedded into objects and be read.

However, we have yet to clarify the conditions in which the proposed technique can be applied. It is especially important for the proposed technique to evaluate the readability of embedded information relating to the structure parameters of fine domains inside real objects fabricated with 3-D printers. Such an evaluation is related to the information volume that the proposed technique can embed into fabricated objects. If the information volume is insufficient to express copyright information, the proposed technique is of no practical use. Even when simple copyright information, e.g., "2016 (c) Masahiro Suzuki," is embedded, around 200 bits are required. Thus, we need to evaluate the readability of embedded information relating to the structure parameters of fine domains inside fabricated objects.

In this paper, we study the readability of embedded information relating to the structure parameters of the fine cavities inside real objects fabricated with 3-D printers and try to clarify the conditions in which the proposed technique can be applied. In the next section, we described the basic concept and principle of the proposed technique. After that, we describe the methodology, explain the results, and provide a discussion of an experiment to evaluate the readability of embedded information relating to the structure parameters of fine cavities inside fabricated objects. Finally, we conclude the paper.

Proposed Technique

Figure 1 is an illustration showing the basic concept of the proposed technique. Digital data for 3-D printing are created with 3-D modeling software, such as 3-D CAD, and copyright information is embedded into the data. When actual objects are fabricated using the data, the information embedded into the data is also embedded into the objects. This information is made readable using nondestructive inspection, such as X-ray photography or thermography, which enable the detection of copyright violations, such as bootleg products. Thus, the copyrights of digital data for 3-

D printing are protected by embedding copyright information into not only the digital data but also the fabricated objects for readability.

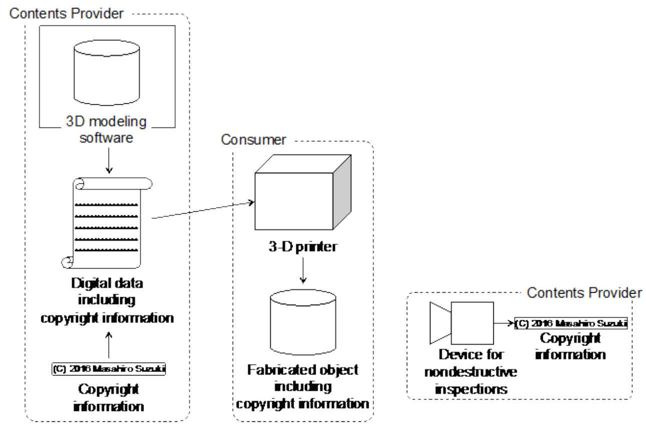


Figure 1. Basic concept of the proposed technique.

Figure 2 is an illustration showing the principle of the proposed technique. In our previous studies, copyright information, which was expressed using ASCII, was encoded as small cavities inside high infill density objects [7] [8]. For example, the existence and nonexistence of cavities at certain positions were represented as “0” and “1,” respectively (see Figure 2-A). The objects, which had cavities inside them, were heated using electric equipment, such as halogen lamps, and the surface temperature of the objects was measured using thermography (see Figure 2-B). The surface temperature at positions where the cavities existed became higher than that at other positions because the cavities blocked thermal flow (see Figure 2-B). Previous studies demonstrated that the existence or nonexistence of cavities can be detected from thermal images and that the embedded information can be decoded from the detected cavities [7] [8]. Thus, thermography can feasibly be used to read copyright information embedded into high infill density objects by constructing their insides with small cavities.

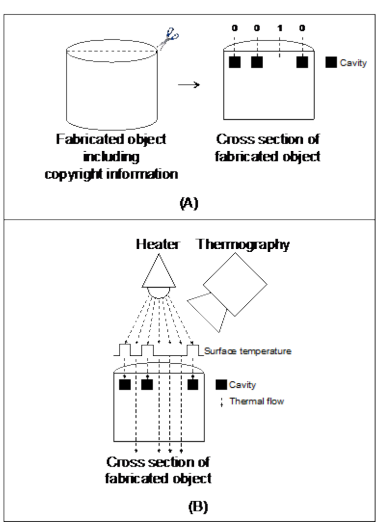


Figure 2. Principle of the proposed technique.

Methodology

We conducted an experiment using four test samples fabricated by a fused deposition modeling 3-D printer using an acrylonitrile butadiene styrene (ABS) filament as the material. Figure 3 is a schematic of the test samples. The top viewed sizes of the cavities were changed in the first test sample (Figure 3-A). The spacing between the cavities as viewed from the top was changed in the second test sample (Figure 3-B). The depths of the cavities themselves were changed in the third test sample (Figure 3-C). The depths of the cavities from the surface were changed in the fourth test sample (Figure 3-D). Halogen lamps were used to heat the samples, and a thermography camera was used to take thermal images. We examined whether the cavities could be detected from the thermal images by the naked eye.

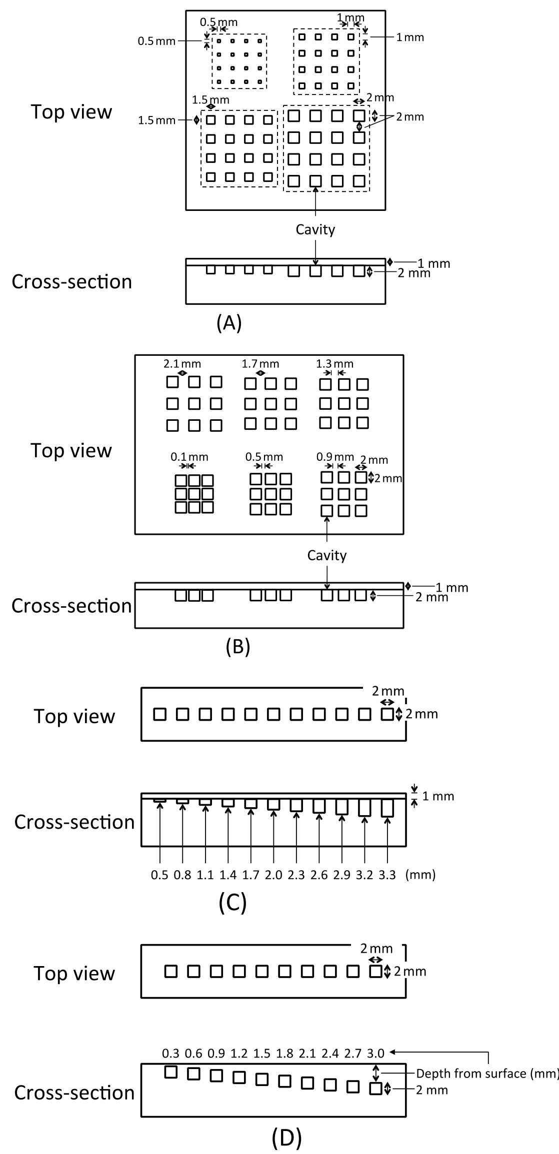
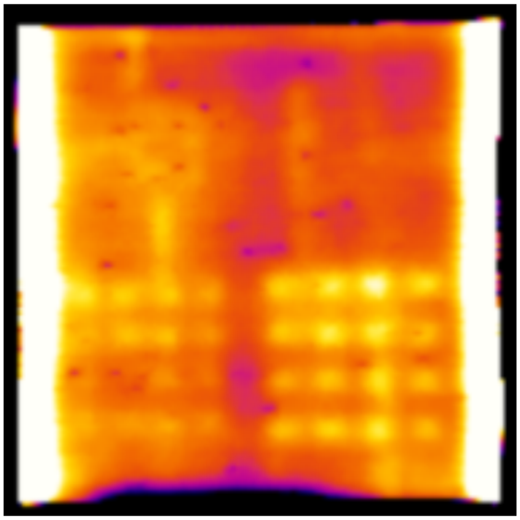


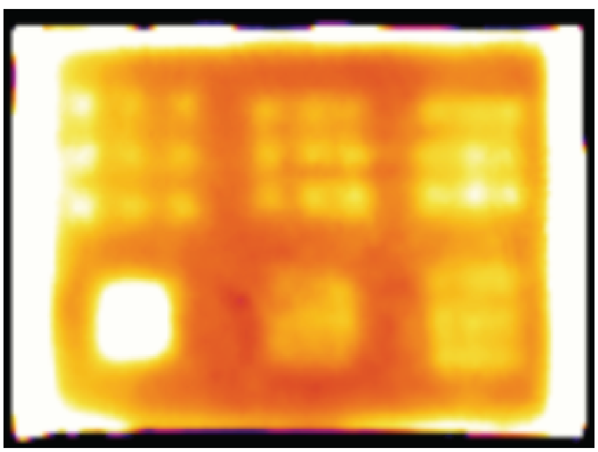
Figure 3. Schematic of test samples. (A) The first test sample. (B) The second test sample. (C) The third test sample. (D) the fourth test sample.

Results

Figure 4 shows thermal images of test samples. Experimental results revealed that a cavity of at least 1.5 x 1.5 mm as viewed from the top could be detected independently of its depth. It was also seen that cavities over 0.9 mm apart could be detected separately. Moreover, the cavities at a depth within 2 mm from the surface could be detected. From these results, the conditions for forming cavities inside the fabricated object are clarified.

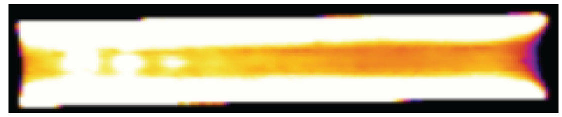


(A)



(B)

(C)



(D)

Figure 4. Results of the experiment. (A) A thermal image of the first test sample. (B) A thermal image of the second test sample. (C) A thermal image of the third test sample. (D) A thermal image of the fourth test sample.

Discussion

Although we demonstrated the feasibility of the proposed technique in our previous studies, we had yet to evaluate the applicable range of the proposed technique. Therefore, in this study, we clarified the conditions for forming cavities inside the fabricated object to embed information into them. We also showed that a sufficient amount of information for copyright (i.e., hundreds of bits) could be embedded if a fabricated object was several centimeters in size. These new findings in this study are crucial to the practical use of the proposed technique.

Conclusion

We evaluated our previously proposed technique of protecting copyrights of digital data for 3-D printing. This technique embeds copyright information into not only digital data but also fabricated objects and enables the information to be read to reveal possible copyright violations. The insides of fabricated objects are constructed with fine cavities to embed information into them. In this study, the readability of embedded information relating to the structure parameters of the fine cavities inside fabricated objects was examined to clarify the conditions in which this technique can be applied. The top viewed sizes of the cavities, the top viewed spaces between cavities, the depths of the cavities themselves, and the depths of the cavities from the surfaces of the objects were changed as experimental parameters. Experimental results clarified the conditions for forming cavities inside the fabricated objects and showed that a sufficient amount of information for copyright (i.e., hundreds of bits) could be embedded if a fabricated object was several centimeters in size.

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References

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

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

[3] P. R. Alface and B. Macq, “From 3D mesh data hiding to 3D shape blind and robust watermarking: a survey,” Transactions on Data Hiding and Multimedia Security II, 2007, pp. 91–115.

[4] T. Modegi, “A proposal of 3D-printing regulation technique for fabricating hazardous devices or copyright violating objects using by polygon matching algorithm,” IEICE Technical Report, vol. 114, no. 33, May 2014, pp. 23–28.

[5] T. Modegi, “Proposal for 3D-printing regulation technique in fabricating dangerous devices,” Bulletin of the Technical Association of Graphic Arts of Japan, vo. 51, no. 4, 2014, pp. 246–255.

[6] K. Wang, G. Lavoue, F. Denis, and A. Baskurt, “A comprehensive survey on three-dimensional mesh watermarking,” IEEE Transactions on Multimedia, vol. 10, no. 8, December 2008, pp. 1513–1527.

[7] A. Okada et al., “Non-destructively reading out information embedded inside real objects by using far-infrared light,” Proc. SPIE 9599, Applications of Digital Image Processing XXXVIII, September 2015, pp. 95992V-1–95992V-7.

[8] 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, 2015, pp. 180–185.

[9] J. Doe, Sample Book, Springfield VA: IS&T, 1999.

[10] T. Jones, "Sample Journal Article," Jour. Imaging Sci. and Technol., vol. 53, no. 1, pp. 1-5, 2009.

[11] J. Smith, "Sample Conference Paper," in Twenty First Color and Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications, Albuquerque, New Mexico, 2013.

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