Embedding and Detecting Patterns in a 3D Printed Object

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***Abstract*—This paper presents a technique for pattern embedding inside a real object fabricated with a 3D printer and a technique of detecting the pattern from inside the real object. The purpose of this technique is to hide information inside a real object by embedding patterns. The patterns are formed inside the object when the object is fabricated. The thermal conductivity of the pattern region differs from that of the other regions. Therefore, the pattern inside the object can be detected using thermography. In this study, we use plaster powder as the starting material, and the object is produced by sintering. However, the pattern region is formed by not sintering it, that is, the pattern region remains as powder. From the experiment, we find that we can detect patterns using thermography when the pattern size is 2 mm x 2 mm or larger, and we confirm the feasibility of this technique.**

Keywords-3D printer, information embedding, thermography, pattern detection.

I. INTRODUCTION

The 3D printer has become compact and inexpensive, and its use is expected to become widespread in the future.

We proposed a technique that embeds patterns inside real objects fabricated by 3D printers that cannot be observed from the outside [1][2]. The embedded patterns express certain information, that is, this technique can embed information inside a real object. We also proposed a technique that can non-destructively analyze the pattern inside real objects and read embedded information [1] [2]. We expect that this technique will be useful for applications such as embedding descriptions of objects inside the objects themselves. Moreover, it is possible to embed copyright information for the design data for a 3D object as a watermark. Related work was reported by K. D. D. Willis and A. D. Wilson [3]. They first made some product parts, one of which had visible pattern, and assembled these parts into one product such that patterned part was inside. However, with our technique, the product that includes patterns inside is formed as one unit, rather than several parts to be assembled later.

In our previous studies [1] [2], we used plastic resin as the material of the object, and patterns were formed by making cavities inside the object fabricated with a 3D printer. We could detect the embedded pattern from the image captured by thermography by utilizing the difference in the thermal conductivity between the cavity and the plastic resin.

This paper proposes a new technique to form patterns inside an object when using plaster as the material for 3D printing. This paper also presents an experiment we conducted to confirm the feasibility of the proposed technique.

II. EMBEDDING AND DETECTING PATTERN IN AN OBJECT

Figure 1 shows the basic concept of the technique we proposed. Since the pattern region is formed inside the object, it is invisible from the outside. The heat conductivity of the pattern region is lower than that of the other regions of the object. Therefore, if the pattern region is formed near the surface of the object, the pattern appears in the thermal image of the surface when the surface is heated because the heat conduction from the surface to the inside is reduced by the pattern region.

Figure 2 indicates the method we propose to form a pattern region whose heat conductivity is lower than the other regions. This technique required the use of an inkjet 3D printer. First, a layer of plaster powder was paved, and it was solidified by jetting binder onto this layer in accordance with 3D data. However, the binder was not jetted on the powder in the pattern region. Therefore, the powder remained in the pattern region. This process was repeated. Finally, the

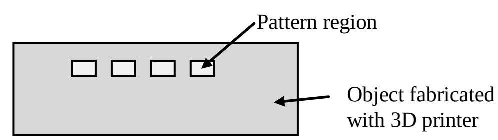

Figure 1. Basic concept of technique we proposed.

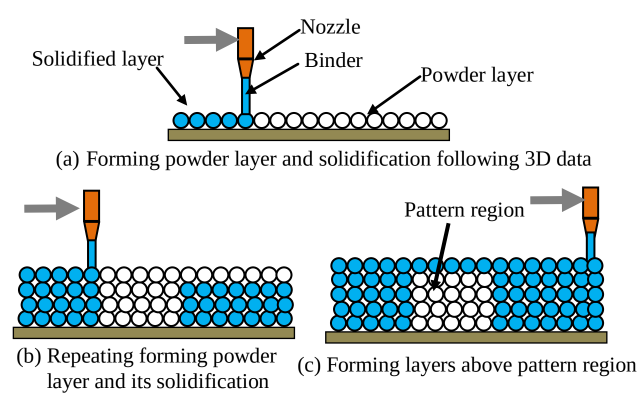

Figure 2. Forming pattern inside object fabricated with 3D printer.

pattern region was covered with a solidified layer.

The arrangement of the patterns express information although they are invisible from the outside of the object. Thermography is used to see the pattern inside. First, the temperature of the surface of the object rises by heating the object. This results in heat conduction from the surface to the inside of the object. Heat conduction is reduced by the pattern region because its heat conductivity is lower than that of the solidified region. This causes the temperature of the surface area above the pattern to increase, and the temperatures of such areas become slightly higher than those of the other areas. Therefore, if we obtain the temperature profile of the surface of the object using thermography, we can determine the arrangement of the patterns, i.e., we can read out the information embedded in the object.

III. EXPERIMENT

We evaluated the feasibility of the proposed technique. Figure 3 shows the sample used in the experiment, which was produced with an inkjet 3D printer. In this experiment, we embedded binary data using small rectangular patterns. That is, the existence or absence of a small rectangular pattern at 25 designated positions expresses "1" or "0". The size of the pattern was changed as one of the experimental parameters.

We investigated to determine if the embedded pattern

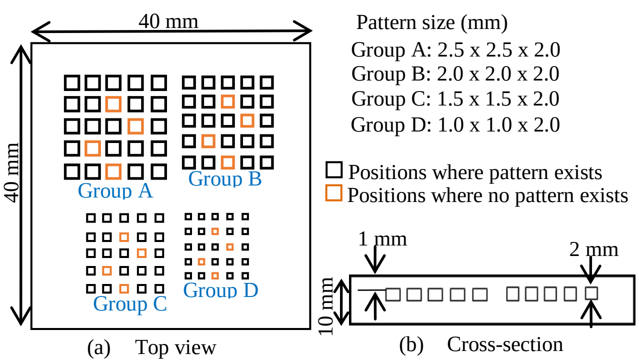

Figure 3. Sample used in experiment

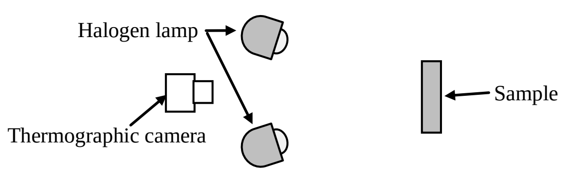

Figure 4. Experimental system

could be detected in the sample image captured using thermography. If we could detect the pattern, we evaluated how small a pattern could be detected and how accurately the embedded patterns could be detected, that is, how accurately the embedded binary data could be read out.

Figure 4 illustrates the experimental system. We used two 500-W halogen lamps to heat the object surface. The lamps were placed at a distance of 10 cm from the sample. Thermography with a resolution of 160 x 120 pixels was used to capture a thermal image of the surface of the object. The temperature resolution of the thermography was 0.1

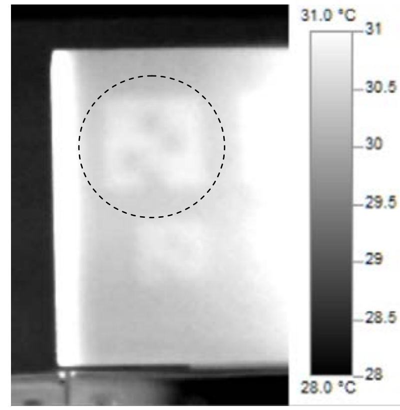

Figure 5. Image captured by thermography

TABLE I. ACCURACY IN READING OUT INOFRMATION

Group (size)	Accuracy (%)
A (2.5 mm x 2.5 mm)	100
B (2.0 mm x 2.0 mm)	100
C (1.5 mm x 1.5 mm)	72
D (1.0 mm x 1.0 mm)	76

degrees.

IV. RESULTS AND DISCUSSION

Figure 5 shows part of the image captured by thermography. The embedded patterns can be seen in the image. The pattern in the dotted-line circle is that of Group A.

Table 1 indicates the accuracy for reading out 25 binary data for each group. For Groups A and B, we achieved an accuracy of 100%, that is, embedded information could be read out with an accuracy of 100% when we used a pattern with a size of 2 x 2 mm or more.

V. CONCLUSION

This paper proposes a new technique to form powder shape patterns inside an object fabricated with a 3D printer using plaster as the material. The purpose of this technique is to embed information using powder shape patterns and detecting them in the object. From the experiment using thermography, we confirmed that the embedded patterns can be detected from the outside and the embedded information could be read out correctly when patterns with a size of 2 x 2 mm or more are used.

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