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3D Printing Technique That Can Record Information Inside An Object As Rewritable

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Abstract

This paper proposes a new 3D printing technique that can fabricate an object in which binary information can be recorded as rewritable. A fused deposition modeling (FDM) 3D printer that has two nozzles was used. An object was fabricated by one nozzle using polylactic acid (PLA) resin, and during the fabrication, domains for information recording were formed inside the object by the other nozzle using the same PLA resin as the object but mixed with iron powder. Since the domains contain iron as magnetic material, information can be recorded by magnetizing them by applying a magnetic field from outside the object. Binary information is expressed by the direction of magnetization of each domain. Experimental results demonstrate the feasibility of this technique. Our technique can be applied in the future to add security and tracking information in the form of magnetic information. This would be valuable in custom manufacturing.

Introduction

Performance improvements in 3D printers have made them smaller, cheaper, and easier to use for those who lack manufacturing skills or knowledge. People who have a 3D printer in their home or office can easily obtain a 3D modeled product by buying its model data on the Internet and printing the product with a 3D printer. Therefore, the diffusion of 3D printers into the consumer sphere is expected to revolutionize logistics and manufacturing industries in the future [1–3].

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. Moreover, the objects can also be used as “things” on the Internet of Things (IoT), for example, by embedding radio frequency identification (RFID) into 3D printed objects, which expands their applications.

3D printers use a unique manufacturing method called additive manufacturing in which objects are formed by stacking thinner layers one by one. This makes it possible to form any structure inside the object. Using this method, we have been studying techniques that can embed information inside an object by forming fine patterns that express some information in the object [4–8]. We have also been studying techniques that can read out such information non-destructively from the outside.

As a non-destructive information readout technology, 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.

We examined a method using thermography [4, 5] and a near-infrared camera [6, 7]. We formed small cavities inside an object as fine patterns at shallow depths from the surface. Since cavities have 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 using thermography.

We also 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 patterns in this case too because most resin materials transmit infrared rays. Moreover, we have studied a technique for forming an inside pattern containing a small amount of fluorescent dye [8]. We demonstrated that since the dye emits fluorescence, high-luminance and high-contrast pattern images could be captured.

Although we developed a technique to embed the information inside 3D printed objects in our previous study, it was information that could only be read out because it was expressed by the structure formed inside. The information cannot be changed once we embed it when the object is fabricated.

If information can be rewritten after it is embedded, its application can be further expanded. For example, security and tracking information can be added in the form of magnetic information in the future, which would be valuable in custom manufacturing. Therefore, this study intended to achieve a technique

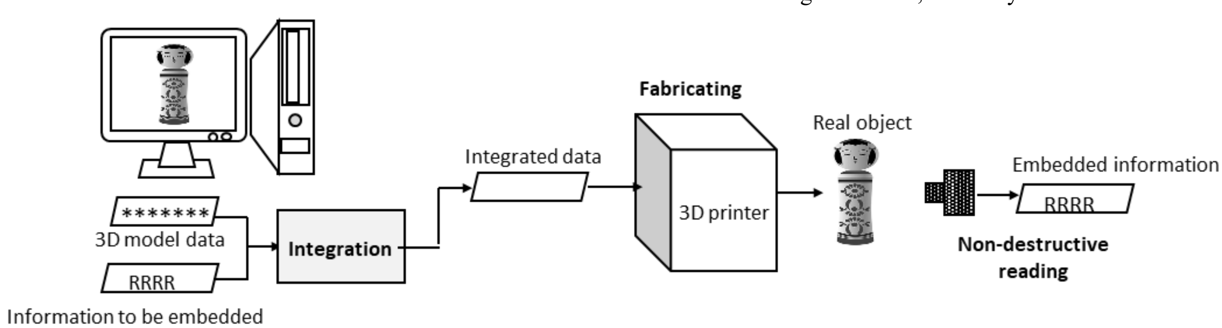

Figure 1. Concept underlying the technique for information embedding into 3D printed object.

that can embed the information inside the 3D printed object as rewritable.

In this paper, we propose a new technique for forming inside patterns containing a magnetic material. Since the inside patterns include magnetic material, it is expected that information can be embedded as rewritable. This technique maintains the ease of using a 3D printer. This paper also describes the experiment we conducted to confirm the feasibility of this technique.

Information Embedding into 3D Printed Object using Magnetic Material

Figure 1 shows the basic concept underlying the technique we proposed and have been studying so far. First, 3D model data are created, and then additional information to be embedded is integrated with the 3D model data. At this stage, 3D model data are modified on the basis of additional information so that fine structures are generated in the object as 3D model data. These 3D model data are input to a 3D printer, and a real object that has the fine structure inside itself is fabricated.

Since the inside structure is formed on the basis of additional information, the structure can be regarded as encoded information. Therefore, the information can be decoded by analyzing the structure from outside the fabricated object. In this way, information can be embedded and read out.

To achieve this for 3D printing using resin as an object material, we proposed a technique that forms information recording domains inside the object. Figure 2 shows the concept of our proposed technique. The fine domains contain magnetic material, so binary information can be recorded by magnetizing the domain by applying a magnetic field from outside. Binary information is expressed by the direction of magnetization of the domains, and the recorded information can be read out by sensing the direction of the magnetization of each domain at the surface of the object.

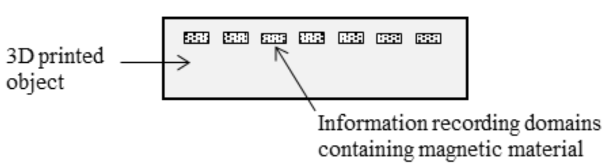

Figure 2. Concept of the embedding technique we proposed.

As material for fine domains, the same resin as the object is used, but it is mixed with iron powder, which works as a magnetic material. The resin mixed with iron has nearly the same melting point as pure resin; therefore, the object can be fabricated in a series of consecutive processes under the same temperature condition.

This forming of an inside structure is performed during the normal process of fabricating an object by a 3D printer, that is, it does not need any additional processes unlike the related research mentioned above. This feature is made possible by additional manufacturing improvements to 3D printers and digital fabrication.

Experiment

Sample Preparation

We conducted an experiment to evaluate the feasibility of the proposed technique. We used a fused deposition modeling (FDM) 3D printer that had two nozzles for producing samples (MUTOH MF-2200D). The samples were fabricated by one nozzle using polylactic acid (PLA) resin, and fine domains in the sample were

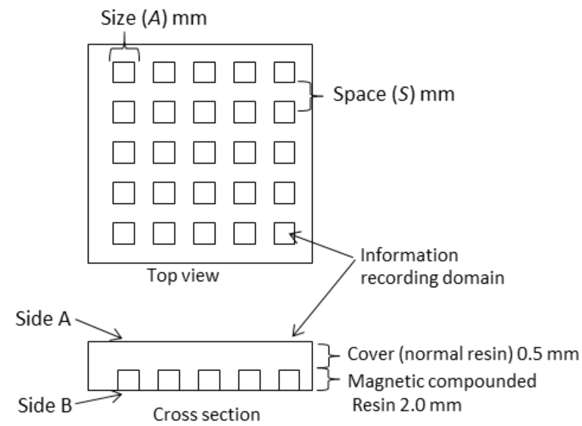

Figure 3. Top view and cross section of the sample.

formed by the other nozzle using PLA resin blended with 25% iron oxide powder (Fe_3O_4).

Figure 3 shows the top view and cross section of the sample. The domains were formed at a depth of 0.5 mm from the surface in Side A. While, in Side B, the domain contacts the surface. Figure 4 shows the designed layout of the sample used in the experiment. Four domain groups, Group A to Group D, were formed by changing the size of the domains and the space between them as experiment parameters: (size, space). They were 1 mm and 2 mm, respectively, shown as Table 1. For example, Group B (1,2) means that the domains were created at a size of 1 mm and have a space of 2 mm between each neighbor domain. Finally, the photos of a real object after fabrication are presented in Figure 5.

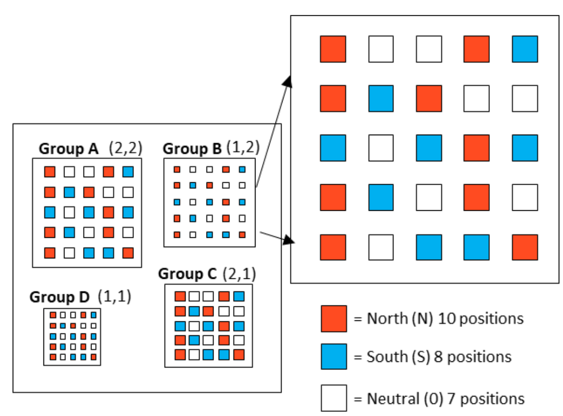

Figure 4. The designed layout of the sample used in the experiment and the direction of magnetization of the 25 domains for each pattern group.

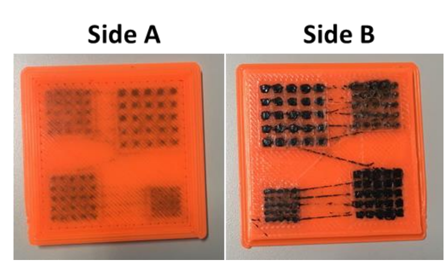

Figure 5. A real sample object: (Left) Side A, and (Right) Side B.

Table 1: Size (mm) and Space (mm) of the magnetic domains vary from Group A to Group D

Pattern Group	Size (mm)	Space (mm)
A	2	2
B	1	2
C	2	1
D	1	1

In practical use, an information recording domain containing magnetic material is embedded in the object. However, in the sample, to investigate the effect of the cover layer, the structure is such that the domain is exposed on one side.

Evaluation

The directions of magnetization of the 25 domains are shown in Figure 4. In Figure 4, ten positions were magnetized by the North magnet (represented in red), eight positions were magnetized by the South magnet (represented in blue), and blank squares with no character indicate the domains that were not magnetized. These directions were the same for all four groups shown in Figure 4.

Figure 6 shows the methodology for magnetizing the domain inside. We magnetized the domains inside the sample from the outside by using a thin columnar magnet with a diameter of 1 mm, shown in Figure 6 (a). Its average surface magnetic flux density was 500 gauss (G). We used a demagnetizer (Hozan HC-31) for clearing the remaining magnetic field each time before starting magnetization. After that, we performed magnetization by using methods for Side A and Side B, as shown in Figure 6 (b) and 6 (c), respectively. Each domain was individually magnetized by bringing one end of the magnet into contact with the surface of the sample above each domain.

The magnetization of each domain was tested in each pattern group and for both sides (Sides A and B in Figure 3). The magnetic field and its direction at both sides of the surface above the domain were then measured by a teslameter.

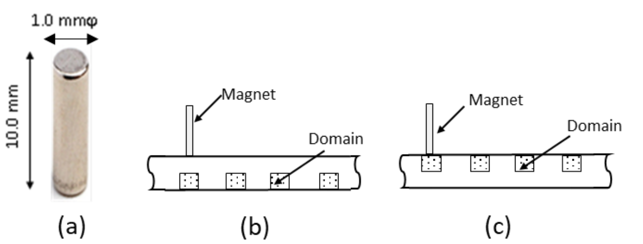

Figure 6. Magnet used for magnetization (a) and method of magnetization for Side A (b) and Side B (c), respectively.

Results and Discussion

Figures 7 and 8 show the experimental results, the measuring of the magnetic field and its direction in Side A and B, respectively. The numerical value in each square indicates the magnetic flux density of the surface above each domain. The unit is gauss.

As expected, in all four groups shown in the figures, we can write the information in the domain and can read it out with perfect accuracy for domains of at least 1 mm in size and with 1 mm of space between adjacent domains.

This minimum domain size and spacing is the same as that of our previous studies where we used non-magnetic material as the domain inside the object. It may be possible to reduce the size of

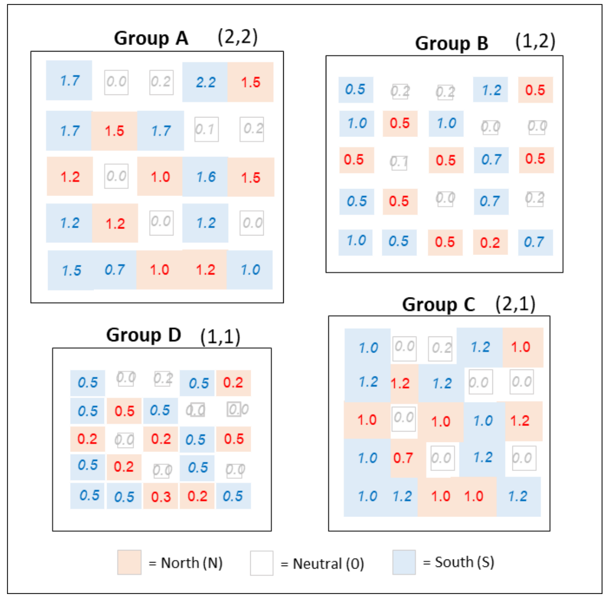

Figure 7. Results of measuring magnetic field and its direction in Side A.

domains without losing the ability to write and read out information with perfect accuracy if a higher magnetic field is applied to the domains, although we would need a thinner and more powerful magnet.

We found that the direction of the magnetization results for all domains are opposite to the direction of the initial magnetized magnet. This enables us to specify information in the future by controlling the direction of magnetization.

Although the value of the magnetic flux in each position is very small if we compare it to the magnetic density flux of the initial magnet, the experimental results show that when the domain size increases, the magnetic flux density on the surface also increases.

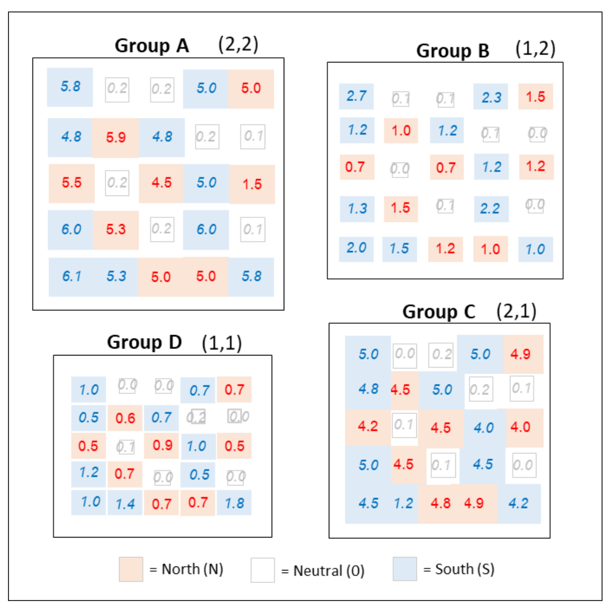

Figure 8. Results of measuring magnetic field and its direction in Side B.

The magnetic field on the surface of Side A is smaller than that on the surface of Side B. We can measure the magnetic flux and the direction of magnetization for each domain correctly. Hence, it implies that we can embed information inside the object because it was made smaller by embedding the domain.

The amount and density of the magnetic resin seems to affect the strength of the magnetic flux stored at the sample. If the amount of magnetic resin increases, the magnetic flux is higher, which can be noticed from the size of the domain. (Technically, the printer cannot extrude material as much when the printing area is too small, that is, 1 mm^2 or less.) The magnetic field should be stronger for domains 2 mm in size than it is for those that are 1 mm in size for both Side A and B. We have to conduct more experiments in the near future to confirm this hypothesis.

Moreover, in practical use, with our technique, we can finish all processes by printing. The melting temperature of normal resin PLA and magnetic resin PLA is almost the same. After we print out the sample with the double nozzle printer, the magnetic filament area has been covered with the normal PLA filament already. No post processes, such as coating and finishing, are needed. This is the advantage of our technique in that steps and production costs can be decreased, leading to mass-production in the future.

However, with the approach in our experiments, we had demagnetized the sample before magnetizing the pattern to the domain in the same positon used previously (different between Side A and Side B). It implies that we can rewrite information to the object by magnetization and demagnetization from the outside of the fabricated object. These results demonstrate that we can successfully add rewritable information to a 3D fabricated object by embedding a magnetic domain inside the object from which information can be correctly read out.

In the future, our technique can be applied to add security and tracking information in the form of magnetic information. This would be valuable in custom manufacturing.

Conclusion

We proposed a new 3D printing technique in which binary information can be recorded inside a 3D printed object by forming a fine magnetic recording domain inside the object using PLA resin. We studied a new technique that can embed information in a 3D printed object by forming fine domains inside the object using resin mixed with a magnetic material. From the experimental results it was clarified that the domains can be magnetized independently for each domain by applying a magnetic field from outside the object. Moreover, it was demonstrated that the direction of magnetization of each domain can be detected from the outside. From these experimental results, we could confirm the feasibility of the proposed technique in which rewritable information can be embedded in a 3D printed object.

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