https://doi.org/10.2352/ISSN.2169-4451.2020.36.12

3D Printing Technique to Make Information inside an Object Rewritable: Effect of Amount of Filament on Readability

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Abstract

This paper presents a technique for embedding information into a 3D object. The technique can rewrite the information non-destructively. Information can be rewritten into the object using magnetization and demagnetization from the outside of the fabricated object. We are studying the factors that can make more clear readability and effective rewritability in embedding data into 3D objects. One factor is the amount of magnetic filament that we use for representing the information in each position. We found that the strength of the magnetic field varies in accordance with the amount of filament. In this way, we can control the size, frequency, and capacity of future embedded information.

Keywords: 4D printing, Rewriteable information, 3D printing, Ferromagnetic, Embedded information, Rewriteable digital tag

Introduction

The idea of embedding, hiding, and attaching information into an object [1] has been used for many purposes. Examples include copyright protection [2], personal authentication or identifying individual things [3], data transferring [4], and near communication [5]. In addition, an increasing number of studies have applied this topic in the field of 3D printing [6].

We have successfully embedded information into objects during 3D printing [7–11]. Our idea can be beneficial to copyright protection, identifying personal or individual objects, etc. These kinds of work can show the specifications or prove the originality of objects, ensuring they do not need to be changed anymore. Hence, it creates permanent embedding.

However, many objects require changing data non-destructively after printing, for example, magnetic and integrated circuit (IC) cards, near field communication (NFC) cards, radio frequency identification (RFID) tags, and other kinds of small data storage. Although we can apply 3D printing in production systems, the post-process still needs embedding in some metal materials, small antennas, or electronic devices, attached to the 3D objects. Finishing everything during the printing would be ideal. That would eliminate the need for post-processing, thereby saving money and reducing the number of complicated steps in the production process. In addition, it could increase the value of products and be hugely beneficial, furthering the revolution in information technology for consumer households, businesses, and factories in such areas as the Internet of Things (IoT), media, and near communication. In the future, everyone should be able to create objects easily using 3D printing and to change the embedded data inside them non-destructively whenever and wherever desired.

We proposed a technique for recording and rewriting information on an object completely using 3D printing in 2019[12]. In that paper, we showed the feasibility of our technique but did not mention any characteristics affecting the results.

Hence, this paper focuses on the strength of magnetic power in 3D objects. We found the relationship between the amount of the magnetic filament, which is the ferromagnetic filament used to embed information codes, and the strength of the magnetic fields that form when we measure the surface of a 3D object. This paper presents the following topics. First, we explain the principle of our technique to embed and rewrite information on a 3D object using magnetization and demagnetization through the magnetic filament on the surface of the 3D object. Next, we present an experiment that demonstrates the effect when we vary the amount of magnetic filament for printing. Then, the results are discussed, and some conclusions on the relationships are presented.

Embedding and Rewriting Information into 3D Objects using Ferromagnetic Filament

Our technique starts with designing a 3D model using a computer with computer-aided design (CAD) software. During model creation, the data strip is embedded inside the object, as shown in Fig. 1. Then, the data tag is hidden inside the object while this object is created by a dual-nozzle 3D printer. When we need to add some information into this 3D object, we apply a strong magnet, affecting the data strip area. Then, the data is written. For the rewriting process, we have to demagnetize the data tag first, clearing all of the information. Then, we magnetize the new data on the data strip. Our data tag now keeps the new information. The process of creating 3D objects that can have information rewritten on them after printing is presented in Fig. 1.

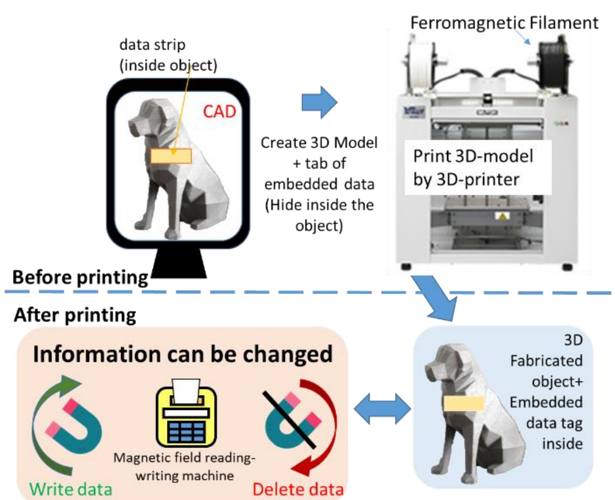

Figure 1. *Principle of our technique for recording rewritable information on a 3D object.*

Ferromagnetic material is important for our technique to enable a 3D object to have rewritable information. In our previous study [12], we tested the feasibility of printing a ferromagnetic filament on a 3D object. We found that the ferromagnetic filament can maintain the magnetic fields far beyond the period after which we use the strong magnet. Moreover, it can be demagnetized many times to eliminate the magnetic fields and can be magnetized again to give the object new ones, for example, with different polarity. However, we have not yet tested the conditions of recording information, such as the factors that affect the strength of the magnetic fields, how long they can keep the data record, what the maximum capacity is that they can maintain, and how we can control future information recording effectively in a 3D object.

This paper shows how we started to test two important factors affecting the information recording: the amount of ferromagnetic filament and the effect of the magnetic strength on the 3D object after magnetization. The details of the experiment are described in the next section.

Experiment: Effect of Volume of Magnetic Filament on the Strength of Magnetic Field in Each Position

We designed three sample models using CAD software—Autodesk Fusion 360. These included different sizes of data strips and different amounts of ferromagnetic filament per data strip at each position. We set the volume of the data strips to 8, 32, and 64 mm3 for each sample. The designed and real models after printing of each sample are shown in Fig. 2, 3, and 4. Darker colors in the data strips show deeper ferromagnetic filament print layers. Notice that all the data strips in the same sample object had the same volume as the ferromagnetic filament. The ferromagnetic filament was black because it was composed of iron oxide (Fe3O4) 25%. All samples were printed using a Mutoh 3D MagiX MF-2200, a dual extrusion 3D printer. One nozzle printed the ferromagnetic filament as a data strip, embedding it on the 3D objects, and the other one printed with polylactic acid (PLA) on the body of the objects. We designed each data strip far from each other, > 5 mm, to prevent the adjacent magnetic field from being degraded around other data strips during magnetization.

The process of writing data is illustrated in Fig. 5. It is based on magnetizing (writing data = recording the magnetic fields) and demagnetizing (deleting data = eliminating all of the magnetic fields). We used a CMS magnetics strong N45 neodymium magnet with a size of 60×10×3 mm (silver) for magnetizing. The magnet (magnetic field > 500 G) was placed on the surface of a 3D object in the data strip area. The north and south poles of the magnet were the opposite side (the north was the upper side, and the south was the lower side, respectively). The contact surface of the magnet on an object was 10×3 mm, mostly covering the area of the data strips. We placed it there for 3 sec. Then, we measured the magnetic fields remaining on the surface of the 3D object using a magnetic meter, Lutron MG-3003SD AC/DC. It read data from the data strips. When we needed to change the magnetic fields on the object, we used the magnet again. However, we had to demagnetize it first by eliminating the entirety of each magnetic field. We placed the object on a demagnetizer (Hozan HC-31-100) for 3 sec, and then we measured the magnetic fields on the object's surface again to ensure that the fields were 0 G. After that, we created the new fields again using the magnet. Of note in our previous study is that the polarity of the magnetic fields on the magnet and on the surface of the object differed and decreased as much as 1000 times (with a data strip of 2×2×2 mm). For example, if we used a strong magnetic field of 2000 Gauss (G) on the south pole, the magnetic field that formed on the 3D-object surface was 2 G. on the north pole. Hence, we could control the data in this situation.

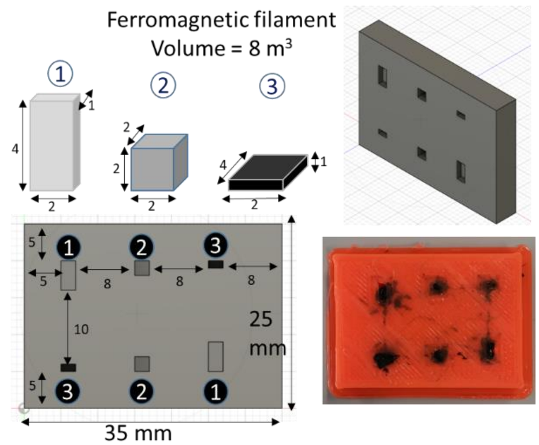

Figure 2. Designed and real models after printing (right) and amount of ferromagnetic filament printing of 8 m^3 at different sizes.

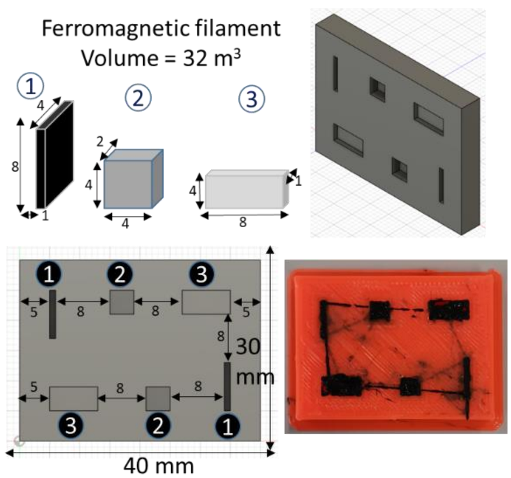

Figure 3. Designed and real models after printing (right) and amount of ferromagnetic filament printing of 32 m^3 at different sizes.

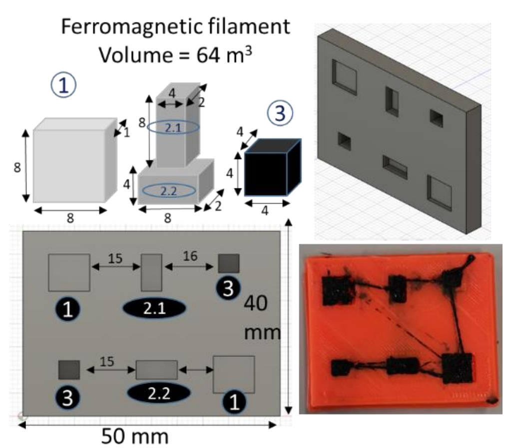

Figure 4. Designed and real models after printing (right) and amount of ferromagnetic filament printing of 64 m^3 at different sizes.

The expected magnetic fields of our magnet are shown in Fig. 6a. The average of the magnet's magnetic fields was 2375 G. The results of the magnetic fields on the surface of each data strip are shown in the next section.

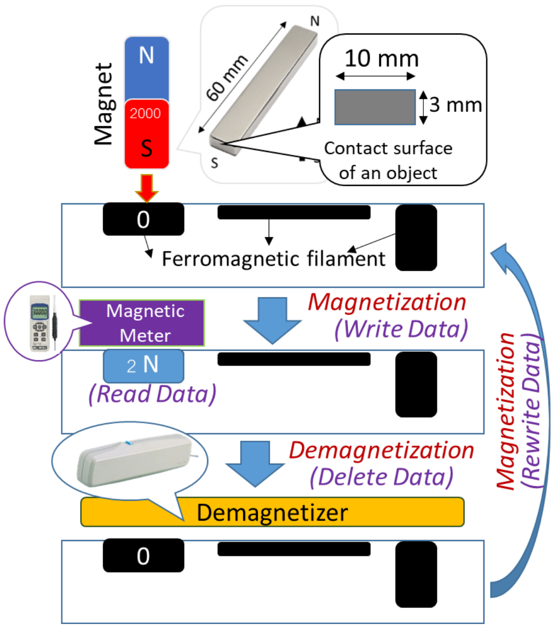

Figure 5. *Process of magnetization (writing data), measuring magnetic field (reading data), demagnetization (deleting data), and re-magnetization (rewriting data).*

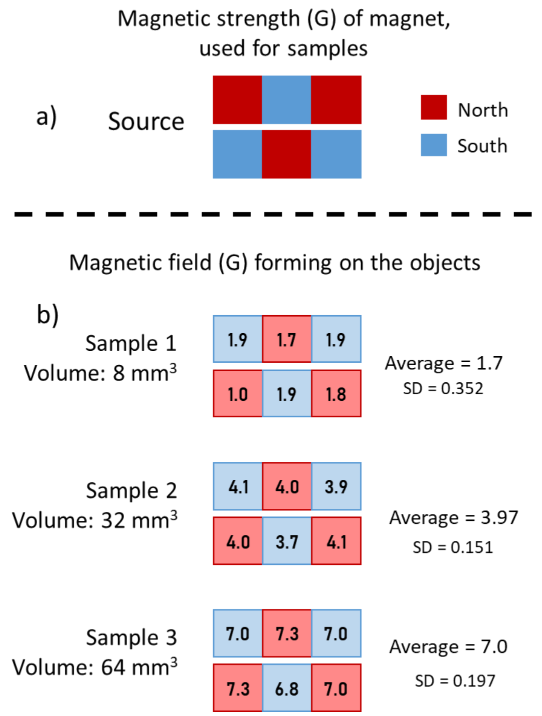

Figure 6. *a) Expected magnetic fields of a strong magnet for an induction data strip and b) remaining magnetic strength results on a 3D object after placing the magnet on the data strip. Red represents the north pole, and blue represents the south pole. The unit number of Gauss (G) refers to the magnetic strength.*

Results and Discussion

We measured the magnetic fields remaining on the data strips (a magnetic meter read data), from the surface of the 3D object. The results are shown in Fig. 6b. These results yielded some interesting factors, ones that will improve the quality and capacity of recorded data using our technique in the future. We herein discuss each point.

Magnetic polar

The results demonstrated that the magnetic fields in the object after magnetization were opposite to the polarity of the strong magnet that we used. Hence, we could control the polarity (types of information) directly using the magnet.

Strength of magnetic fields

In the same sample that had the same amount of ferromagnetic filament (we controlled it by keeping the same volume), we noticed that the magnetic strength (Gauss: G) of every stripe was approximately the same, while the sizes and shapes of the strips were completely different (see the designs in Fig. 2, 3, 4).

When we analyzed each sample, the magnetic fields depended on the amount of ferromagnetic filament that we used. They did not depend on the size, shape, contact area, or surface of the strips' design.

This demonstrated that we could design the data strips using many styles depending on the purpose. In any case, we were only concerned with controlling the volume of the data strips (amount of ferromagnetic filament) to enable the recorded data that we created to have high quality and quantity.

Our analysis of the three samples revealed that the magnetic strength on the objects accrued as the amount of ferromagnetic filament increased on the strips. The relationship between them was almost perfectly linear, as can be seen from Fig. 7. Equation 1 was used to generate the results. (R2 =0.9999).

$$y = 0.0959x + 0.9203 \tag{1}$$

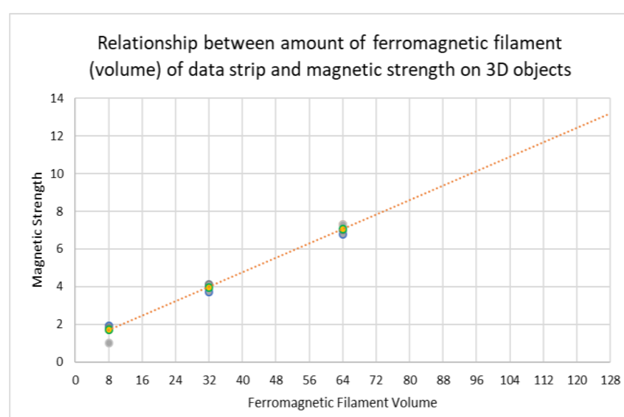

Figure 7. *Relationship between amount of ferromagnetic filament (volume) in data strip and magnetic strength on 3D objects. The orange line shows the magnetic strength needed to maintain the data.*

Method to represent the data

The results demonstrate that we can use the ferromagnetic filament to maintain the magnetic field for a long period after magnetization. Moreover, the results showed that we can increase the magnetic strength by increasing the amount of ferromagnetic filament, controllable by increasing the volume of the data strips. This gives us advantages in designing data strips to fit many future purposes.

With these properties, we can represent information using the formation of the magnetic field with ferromagnetic data strips, illustrated in Fig. 8. These figures show the cross-section of a 3D object containing three bits, which were printed using the ferromagnetic filament embedded as a data strip inside three positions. It can be magnetized at each position to induct the magnetic poles forming in each data strip using three patterns, neutral, north, and south. We can represent data using this kind of *magnetic polarity*.

In practice, we use only two patterns, such as the north pole being 0 and the south pole being 1 (or the reverse). The neutral pattern refers to no data, such as when information has yet to be written (the demagnetization stage).

This method has the reliability of writing and reading data. We checked by assigning the magnetization of north or south to each magnetic filament position. Then, we checked the expected polar which appear on the sample in each position. We found that every position was all correct, although the adjacent positions. Moreover, when we left the time for a period and measure the magnetic power again, the magnetic power was still can be read as the first time. This result showed that our technique is reliable for keeping data in future. However, we will confirm this property completely in our future work also.

With this method, data can be rewritten whenever we need them with loops of demagnetizing and magnetizing, as shown in Fig. 1. This way very easily allows for reading information very accurately and quickly by remembering the position of the recorded data.

The advantages of our proposed method are 1) Familiar Rules for Keeping Data, a fabricated 3D object can maintain information by applying the rules of conventional information storage, 2) Reusable Items, these objects can be reused several times, just by changing the information inside them. 3) Clarity, we can increase the clarity / strength of data reading by increasing the volume of the data strip. That is not dependent on the shape and size of the strip. Thus, this freely enables the benefit of design to fit one's purposes. 4) Capacity, we can keep as much data as we need using this technique. The capacity depends on the amount of the ferromagnetic filament that we can print into the object, which can be controlled by the volume of the data strip.

One idea that will be able to apply our idea in practical is the data tagging in 3D printed object. To verify 3D printing application, the real 3D objects would be built, while the ferromagnetic filament would be inserted during printing. Then, we can write data to the tag by magnetization. We can use the tag by reading information using magnetic meter. Finally, we can reuse this tag repeatedly whenever we need by demagnetization. These process would be confirmed all again in the future in the part of application of this research.

The limitation of our method is contamination of the magnetic field during magnetization. Such contamination could cause our strip to lack continuity. In the future, if we can control the induction magnet better, we can reduce the size, frequency, and area of the embedded data strip.

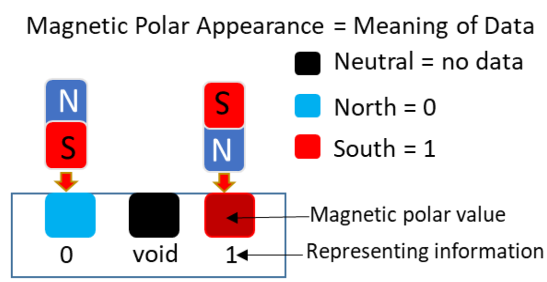

Figure 8. *Data represented by magnetic poles: effect of a strong magnet to assign three patterns per one data position strip, such as neutral (black) = no data, North (blue) = 0, and South (red) = 1.*

However, another factor that we found and concerns us is the power and strength of the induction magnet. We found that a stronger magnet can induct the ferromagnetic filament so that it maintains a higher magnetic strength. Therefore, this is an important factor that affects the recording information. We will study it more closely in the near future.

Conclusion

We proposed the new ideas of recording and rewriting information non-destructively into 3D objects. One of the advantages of our technique is that it requires no post-processing after printing. The data strips are embedded during printing. This can substantially save time and money for production in households, businesses, and factories in the future.

The key to our success is that we were able to rewrite the information in 3D objects with ferromagnetic filament to embed data strips inside the object. The properties of this material enable magnetization (writing data) and demagnetization (deleting data) using the induction of magnetic fields. We actively studied the factors that affect the quantity and quality of written information into the data strips. One important factor was the amount of ferromagnetic filament used for the volume of printing. For same volume of printing, the magnetic strength formed on the surface of a 3D object could be the same. Increasing the volume of ferromagnetic filament increases the magnetic strength in a nearly perfect linear way. Thus, the clarity of data reading also increases. We also proposed a method for representing data with the formation of magnetic fields from ferromagnetic data strips on 3D objects, and the process is easy and convenient. We expect that our method will be beneficial for future IoT creation, enabling home-made designs and data strips that can be used for many different purposes, furthering the information revolution for countless users.

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