https://doi.org/10.2352/ISSN.2169-4451.2018.34.202

Information Embedding in 3D Printed Objects Using Metal-Infused PLA and Reading with Thermography

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Abstract

Digital fabrication has the potential to innovate manufacturing and logistics in the near future. An attempt to increase the value of real fabricated objects by embedding information and including copyright protection is often proposed. We present a new technique for embedding information using metal fused materials (Copper powder-infused PLA) to form a fine structure inside the 3D printed objects. Then, information can be detected nondestructively by thermography. Our experiment proved that a binary code array of metal-infused material can be successfully printed and embedded inside a sample of fabricated 3D based objects (ABS). In the thermal image, the implanted structure areas were clearly observed with temperature conditions different from the surroundings. We also studied the factors that influence the quality of readouts, such as how deeply infused-metal is embedded from the surface, the colors of the filament substances, and the clearance of the image binary code compared to previous methods. The best condition was embedding metal-infused material 1 mm deep from the surface. Moreover, the color of the printing filament had no effect on the quality of the read-out information. These results mean that we can increase the value added to various kinds of objects fabricated with 3D printers more conveniently.

Introduction

Three-dimensional (3D) printing has been attracting a great deal of attention. There has been an increase in research and development [1-2]. Initially, it was mainly used as rapid prototyping technology. However, it has recently been used for manufacturing end-products [3] with materials such as resin, plaster, metal, and even food [4]. Since some types of 3D printers are inexpensive and compact, it has become possible for people to buy them as home devices. Consumers are easily able to create products at home just by purchasing data through the Internet and self 3D-printing. Therefore, a physical distribution stage is no longer needed. This is why digital fabrication has the potential to innovate manufacturing and logistics. Repeated proposals to embed information inside real fabricated objects have been made. Willis and Wilson [5] made some product parts, one of which had a visible pattern. They assembled these parts into one product so that the patterned part was inside. They read out the internal patterned information using a terahertz wavelength light. However, it was too complicated and impractical to use in household 3D-printing. Therefore, we have been working on a technique that forms fine pattern structures inside of objects with a 3D printer. In contrast to previous methods, our technique eliminates additional processes by integrally forming the fine structures with the body, utilizing additive manufacturing that is a feature of 3D printers. The internal pattern structures give information and are not visible outside of the objects. We have also been studying a technique that uses thermography [7][6], near IR [8], and X-rays[9] to nondestructively read the embedded information from the outside..

The main purpose of these studies was to add extra value to the objects produced by 3D printers. For example, we can embed information that usually comes with newly purchased products (e.g., user manuals) into the objects. Another example is when a part created by a 3D printer needs to be rebuilt or replaced. The details are easy to obtain by embedding the file information into it. Moreover, we can embed watermarks to protect the copyright of the original objects digital data. Although this is similar to conventional digital watermarking for digital content [10], the final product is not digital data but a real object. Therefore, a watermark needs to be embedded into the real object.

In this paper, we explain how our technique for embedding information into a real 3D fabricated object uses metal fused materials (Copper powder-infused PLA) to form a fine structure inside 3D printed objects and how we are able to detect information by thermography. We describe the basic concepts of embedding information inside 3D objects and reading that information out nondestructively in Section II. The details of our experiments to embed an 8 by 8 array of metal-infused materials into samples of the fabricated 3D objects (ABS)are explained in Section III. We show the results captured by thermography and our discussion in Section IV. Finally, we give our conclusion in Section V.

Basic Concepts

We studied the techniques for embedding information inside fabricated objects and nondestructive read-outs so far [6] - [9]. Figure 1 shows the principles of the overall process of embedding information until it is read out. The details of each step are described as follows.

Information Embedding Inside 3D Printed Object

The intended information is embedded inside a 3D object through the digital files. The 3D printing process usually begins by making a 3D model with CAD software. The information is added when the owner creates a 3D object. After that, the digital file of the objectwhich contains the intended hidden informationis integrated and saved as the most well-known output file, .slt. Before 3D printing a model, the slicer software will slice the model and generate it file for communicating with the printer directly. After that, when they start printing, the intended hidden information will be printed out with the model, as the same piece of an object.

Figure 2 presents the schematic of a printed object that includes implanted information. The contents of the information-integrated with implanted informationare embedded as an array

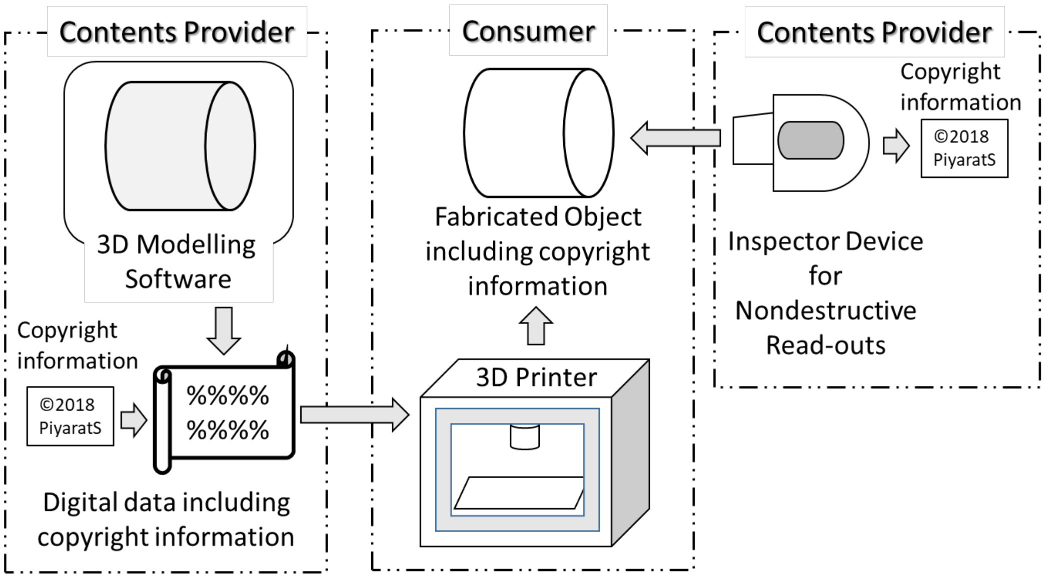

Figure 1. *Diagram of information embedding inside 3D printed object technique*

structure inside an object before generating the g-code. These array structures comprise a number of rectangular prism geometry, the cross-sectional shape of which could be changed into another shape. For the simplest decryption,8-bit data is translated into human language characters using ASCII. Thus, we can represent the information by ASCII code patterns and embed them inside the 3D model in the digital file with this schematic.

In our previous research [6] - [9], we used the pattern structures as the cavities, or pure space, inside the 3D object. We would like to use our research to improve the method of embedding information inside 3D fabricated objects. So, we tried to check the feasibility of embedding the code structure using metal-infused material instead.

To read out the implanted information without any damage to the model, we can use some specific photography techniques to capture images of the information inside. Then, image processing techniques are used to help to read the information code. The traditional nondestructive detection methods for implanted structures are thermography [6][7], radiography [9], magnetography [11], and sonography [12]. With a different method, the different wavelength sources and sensors are selected and applied in different cases.

Nondestructive Extracting Information by Thermography

The thermography method was selected in this study because the heat source is the simplest and cheapest generator when compared to electromagnetic waves, magnetic fields, and sound waves. With the thermography inspection method, the thermal properties of the implanted structure material must be different enough to distinguish the implanted structure from the product body. The most concerned property includes density, specific heat capacity, and heat conductivity. The thermal images of the printed objects are taken when the objects surfaces are heated. The surface temperatures of products indicate the implanted structure due to different thermal properties. The heat conduction rate in the same direction as the normal vector of an implanted structure plane is blocked or developed, and the surface area above or under the temperature of the implanted structure differs from the surrounding area. Each prism geometry represents a digit of the binary value, which is the most popular data basis for computer-based devices and other electronic devices. Conclusively, the temperature difference in the thermal images is the representative of binary value, which can be decoded as the intended hidden information in human language. The schematic of the thermography method is displayed in Figure 3.

Experiments

We measured the feasibility of embedding metal-infused PLA material inside a 3D fabricated object. We focused on three

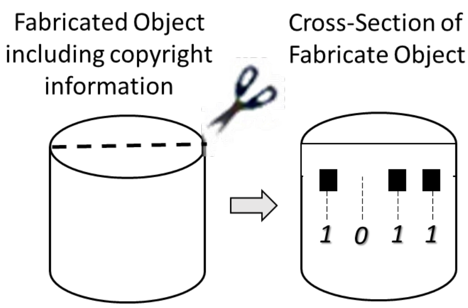

Figure 2. *Printed object including implanted information*

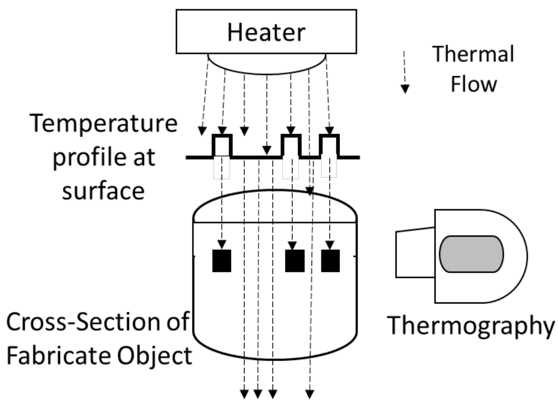

Figure 3. *Embedding information observation with thermography approach*

things: First, we compared the characteristics of the thermal images from embedding metal-infused PLA material and from cavities as the implanted structure. Second, we studied how the depth of embedded structure factors in, from the external surface to the implanted structure. Thirdly, we checked the effect the color of the base structure has on the quality of the read-out . The details on the experimental design and setting are as follows.

Experimental Design

We designed three experiments for checking the feasibility when embedding metal-infused PLA at different depths and for checking the effects of using different base colors. Our first experiment concerned the feasibility of our new method compared to the previous method [6] -[7]. Thus, it compared checked the pattern structure of both kinds of implanted materials between the metal-infused PLA and the cavities. The second experiment compared the effects of implanting between 1 mm and 2 mm from the surface. Finally, we checked howor, indeed, ifcolor affects our technique.

The geometry of all the sample objects was an 8 by 8 array of metal-infused material or cavities implanted [as implanted structure into — onto — into?] a flat plate, which was printed from ABS material. The geometry of our sample objects is displayed in Figure 4 with different views. The thickness of the filled material in the implanted structure and the implanted space was fixed at 2 mm. The distance between the surface and the implanted structure was fixed at 1 mm and printed with black ABS filament except for when we compared a 2-mm surface depth in experiment 2 and a blue sample in experiment 3.

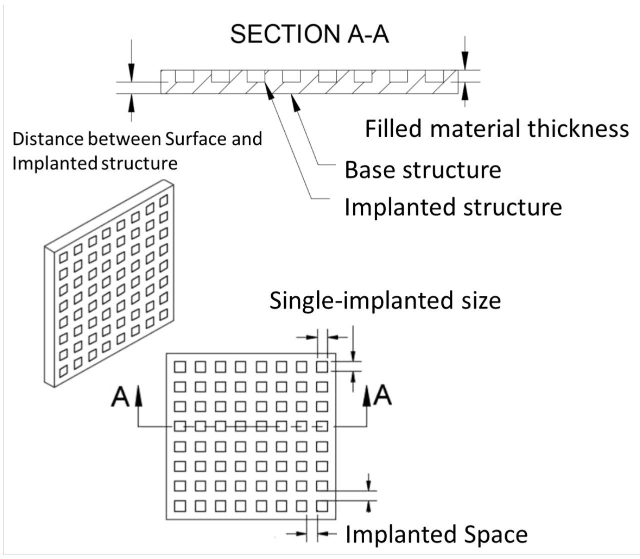

Figure 4. *Sample Design: a) Cross-sectional A-A view of sample objects, b)Top and isometric view of sample objects*

Experimental Setting

We printed out all sample objects with a dual-nozzle printer, a Mutoh Value3D MagiX 2200D (shown in Figure 5a). Two materials were printed as the same objects. The body structure used normal ABS filament (seen in Figure 5b), and the implanted structure used Copper powder-infused PLA filament (see Figure 5c). After that, all the samples were heated. Then, images were captured with thermography using a Testo 885-2.

The thermography set-up (displayed in Figure 6) was comprised of:

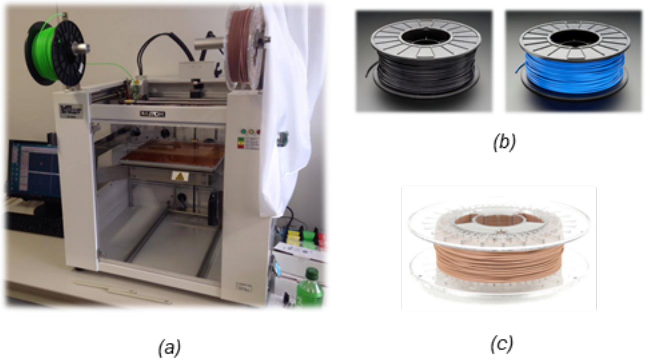

Figure 5. *Printing Setup: a) Dual-Nozzle Printer, b) Normal ABS filaments: (Left) Black and (Right) Blue, c) Copper powder-infused PLA filament*

- *Camera* It was a thermography camera, which senses the temperature of the object in each surface area
- *HalogenLamps* for heating sample objects,
- *ElectricFan* for cooling sample objects down,
- *ObjectStand* for adjusting the object position.

The objects were set in the thermography system one by one to take their thermal images, and these thermal images were compared to examine the effects of each factor at the end.

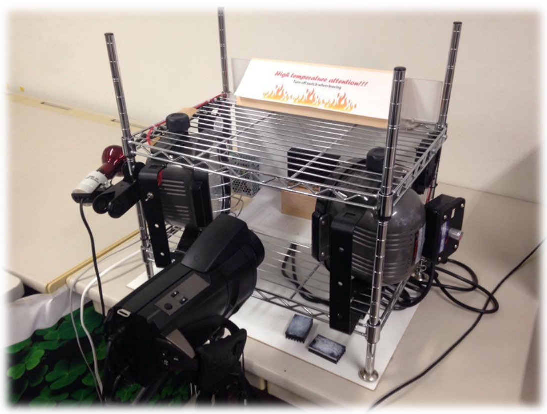

Figure 6. *Thermography Setup*

Results and Discussions

In this study, we measured the feasibility of embedding metal-infused filaments instead of cavities inside of fabricated objects. We did three experiments. The results and discussions in each experiment are described as follows.

Embedding Metal Fused Materials

We used the Copper powder-infused PLA as the metal infused materials, embedding the code pattern inside the 3D object. Figure 7a displays the real samples that were produced from the 3D printer, in both metal-infused (left) and (right) cavities. The resulting thermography photos in Figure 7b show the patterns of the implanted structures, comparing the metal-infused material (left) and cavities (right).

The results showed that implanted structures can be read out by thermography in metal-infused models as well as when using a cavities pattern. However, the heat conductivity and transferring ability of metal are better than plastic filament (ABS) and better than air (cavities), respectively, which allows the heat to

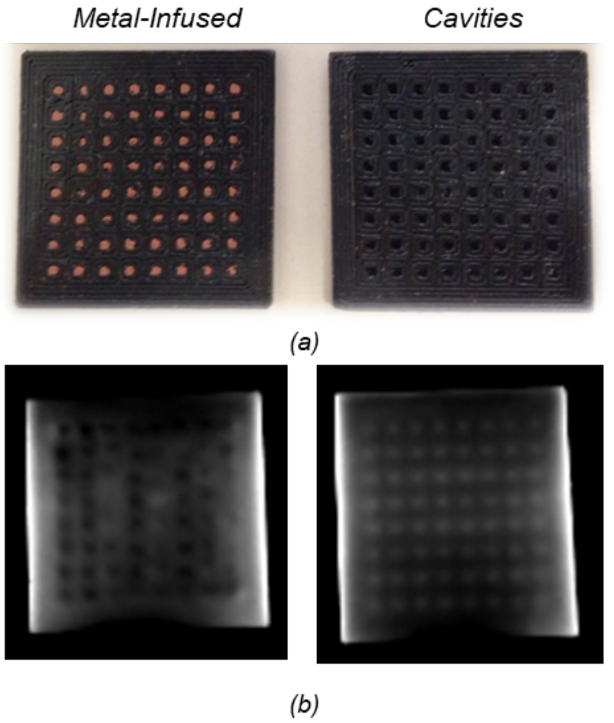

Figure 7. Results of Embedding Metal-Infused Material: a) Photo of fabricated samples, embedding the information pattern with different materials inside: (Left) Copper powder-infused PLA (Right) Cavities, b) Their thermography results: (Left) Metal-infused implanting pattern (Right) cavities pattern thermography

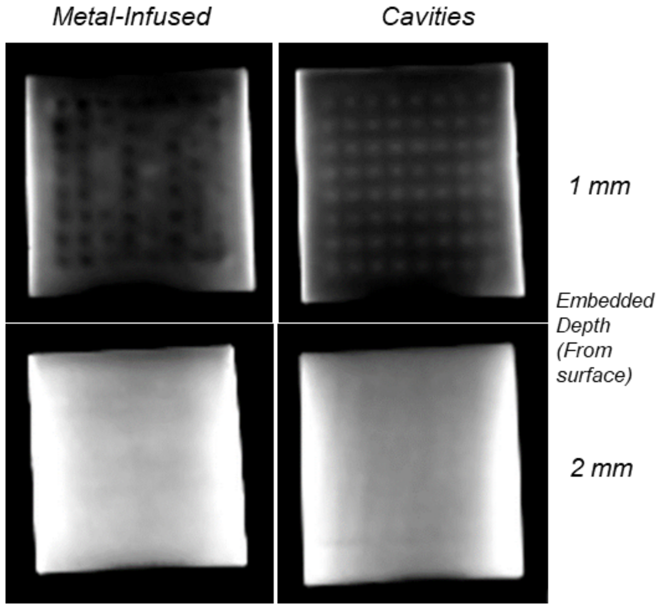

Figure 8. Thermography of implanted structures at different depths from the surface, comparing Copper powder-infused PLA and cavities

flow inside more quickly. It makes the pattern of metal areas become colder than others. For this reason, the pattern structures of Copper powder-infused PLA become darker than their surroundings. On the other hand, heat transfers and collects in cavity areas better than the body structures. Thus, the cavities pattern is brighter than the body. In summary, we can say that, between metal-infused and cavities, both thermography images are the inverse of each other.

Although the sharpness of the information represented in the images taken from the samples with metal-infused material implanted structures was lower than in the images taken from the samples with cavity-implanted structures, we could not conclude that the latter issued higher sharpness than the former because the metal-infused material could not be printed as an implanted structure as perfectly as the 3D model in this study. The sharpness of the information represented decreased since the samples were printed.

In the future, we will have to adjust the time to expose and use the interpreted process of image processing suitably in order to improve the images for the information extraction code. By doing so, we can successfully embed the information code inside the real 3D model of a fabricated object by using metal-infused material as well as a cavities pattern.

Effects of Depth on Embedded Information

For this experiment, we studied the effect the distance from the external surface to the implanted structure has on the quality of read-out information in thermal images. We tested this at 1 and 2 mm implanted depths, comparing metal-infused [material?] and cavity structures. The results are displayed as the thermal images as Figure 8.

From Figure 8, we can see that the information patterns were clearly captured by thermography at 1 mm embedded depth using both metal-infused material and cavities inside. The 2-mm implanted depth was too deep to capture the thermal pattern image. An effect was caused by the multi-dimensional properties of heat conduction, and larger distance in any direction had a lower heat conduction rate in those directions. When the distance between the surface and the implanted structure increased, the conduction rate in the thickness direction of the samples dropped but the rate in the transverse direction remained the same. Therefore, the heat from the surrounding surface area could be transmitted to each information representative prism when the implanted structure used metal-infused material. In addition, the heat from the surface area contiguous with the representatives could pass to the base around the representatives when the implanted structure was cavities. Thus, when heat transfers to the implanted layer, the temperature of the plastic on the surface is too high to completely blind the temperature of material inside when implanting at deep depths. For this reason, the surrounding plastic is in the same barrier blocking heat from the implanted material inside. This means that a distance of about 1 mm was an appropriate geometric condition for implanted structures in this case. However, a less than 1-mm implanted depth is suitable for embedding information pattern structures inside 3D models to collect all the hidden read-out code information from clear images.

Effect of Color on Base Object Embedded Information

Our last experiment examined if our method varies depending on the color of the base object. Therefore, we printed two samples from the same file using the black and blue ABS filaments shown in Figure 5b. Both samples and their thermography images are displayed Figure 9.

The colours of the base structure did not affect the results. The temperature-measuring principle of the thermal camera and the transparency of the base structure satisfactorily explain this effect. The thermal camera detects the emitted infrared radiation of objects to evaluate their temperature using calibration with radiation of black body. The Wiens displacement law [14] and

Stefan-Boltzmann law [15] are decribeed briefly as equation 1 and 2 , respectively.

The Wien's displacement law is an equation that describes the relationship between the temperature of an object and the peak wavelength or frequency of the emitted light.It provides the wavelength where the spectral radiance has maximum value. This law states that the black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature.

$$\lambda_{max} = \frac{b}{T} \quad (1)$$

Where λ_{max} is the peak of the wavelength. b is the Wien's displacement constant, $(2.9 \times 10^{-3} mK)$ and T is the absolute temperature in Kelvin.

The StefanBoltzmann law describes the power radiated from a black body in terms of its temperature. It relate to entropy of an ideal gas to the quantity. Specifically, the StefanBoltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time, also known as the black-body radiant emittance, is proportional to the forth power of the absolute temperature.

$$\mathrm{P} = \sigma \mathrm{A} \varepsilon \mathrm{T}^4 \quad (2)$$

Where, is the power radiated ($Watts$) by the substance, σ is the Stefan-Boltzmann constant,$(5.6696 \times 10^{-8} W/m^2K^4)$. A is the surface area of the substance in meters. ε is the emissivity constant, $0 <= \varepsilon <= 1$. The value of ε depends on the properties of the substance surface from which the radiations are to be transmitted. T is the surface temperature in K.

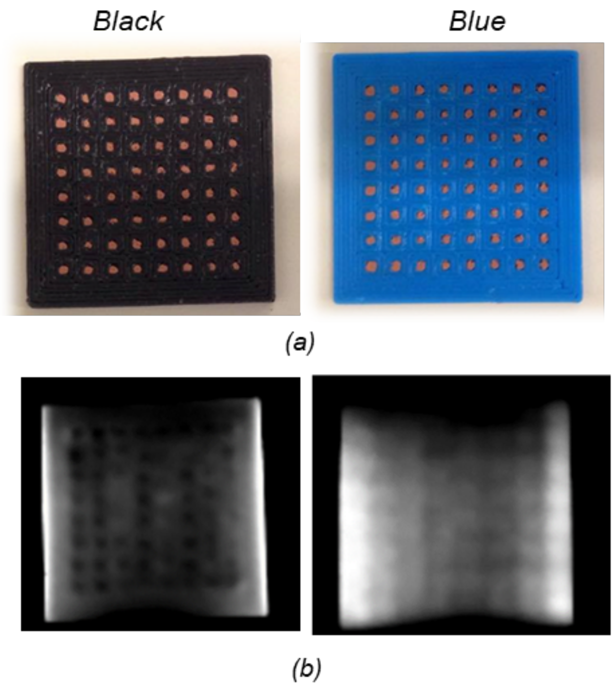

Figure 9. *Thermography of implanted structures in different colors base: a) Photo of Copper powder-infused PLA when is embedded with a fabricated object in different colors, b) Metal-infused implanting pattern thermography, c) Cavities pattern thermography*

Visual inspection showed that the transparency of the base structure in both colors was different although they were ABS. The black base structure was dense though it was more translucent than the blue base structure. If the base structure is transparent, the radiation from the halogen lamps that include infrared radiation could pass through it and be reflected by the metal-infused material. Hence, the camera correctly measured the summation of the emitted radiation and reflected radiation, not just the emitted radiation. Given that, the measured temperature in the thermal images taken of the information representative was higher than it was. However, base structures with translucent properties can be used with metal-infused material implanted structures, though the characteristics of the thermal images that are taken are different due to several mechanisms.

Conclusion

We succeeded in embedding and nondestructively reading out information that was printed using different materials between the binary code array and the base object using thermography. Thermal images that were clear with high contrast between the area of the implanted structure and the base object resulted from the surface temperature of the metal upper part being lower than the surrounding areas. The metal had high thermal conductivity, so the heat of the surface flowed quickly to the inside. Consequently, the different temperatures in each area were captured as thermal images that represent the binary values that could later be decoded as information in human language.

We also studied the factors that influence the quality of read-out information, such as the depth of embedding infused-metal from the surface, colors of the filament substances, and clearance of the image binary code when compared to previous methods. The best condition was embedding metal-infused material 1 mm from the surface. Moreover, the color of the printing filament had no effect on the quality of the read-out information. These results mean that we can increase the value added to various kinds of objects fabricated with 3D printers more conveniently.

References

[1] Zhen Chen, Hindawi, 2017, ID 7849670, 19 p. (2017). https://doi.org/10.1155/2017/7849670.
[2] Christian Weller, Robin Kleer and Frank T. Piller, Int. J. Product Econ., 164 , 43. (2015).
[3] Frazier, W.E. J. of Materi Eng and Perform, 23, 1917. (2014). https://doi.org/10.1007/s11665-014-0958-z
[4] Matthew Lanaro, David P. Forrestal, Stefan Scheurer, et al ., J. Food Eng. , 215, 13. (2017)
[5] Karl.D.D. Willis, Andrew.D. Wilson, ACM Trans. Graph., 32, 4 . (2013)
[6] Masahiro Suzuki, Piyarat Silapasuphakornwong, Kazutake Uehira, Hiroshi Unno, Youichi Takashima, Proc. 10th Int. Conf. Com. Vis. Theory App.VISAPP, 3, 180. (2015)
[7] Piyarat Silapasuphakornwong, Masahiro Suzuki, Hiroshi Unno, Hideyuki Torii, Kazutake Uehira, Youichi Takashima, IWDW, 232. (2015)
[8] Kazutake Uehira, Masahiro Suzuki, Piyarat Silapasuphakornwong, Hideyuki Torii, Youichi Takashima, IWDW, 370. (2016)
[9] Masahiro Suzuki, Piyarat Silapasuphakornwong, Youichi Takashima, Hideyuki Torii, Kazutake Uehira. IEICE Trans. 100-D(6), 1364. (2017)
[10] Frank Hartung, Martin Kutter, Proc IEEE., 87, 7, 1079. (1999)
[11] Jing Li, A. A. van Ballegooijen, Don Mickey, The Astrophysical Journal, 692, 2, 1543. (2009)
[12] A. T. Stavros, D. Thickman, C. L. Rapp, M. A. Dennis, S. H. Parker, G. A. Sisney, Radiology,196, 1, 123.(1995)
[13] Frank.P. Incropera, Davit.P. Dewitt, Wiley . 2011.

[14] Willy Wien, Physik., 288, 5, 132. (1894)
[15] Josef Stefan, Vienna, 79, 391. (1879)
[16] Ludwig Boltzmann, Annalen der Physik und Chemie, 258, 6, 291. (1884)

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