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Embedding information on additively manufactured parts using Mondrian patterns

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Abstract

With Additive Manufacturing (AM), parts having complex geometries can be produced easily compared to the traditional manufacturing methods. AM gives the opportunity to produce those complex parts in a very straightforward manner. This simplification eases embedding of different structures, patterns or assets to the part without the burden of additional manufacturing processes. It has been observed that the most common approach for this purpose is to use QR codes. This article discusses a different method combining science and art together. A simple coding approach inspired by the Dutch painter Mondrian, who is known to have paintings consisting of grids and contrast colors, has been developed. In this paper, details of the proposed method to embed information onto the AM parts are presented and the results are discussed.

Keywords: Additive manufacturing, Embedding information, Mondrian, FFF

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1. Introduction

Additive Manufacturing also known as 3D Printing or Rapid Prototyping (RP) is a manufacturing method where the part is produced by adding successive layers of material instead of material removing approach in the conventional manufacturing processes.

With AM, complex geometries that are impossible to produce on the conventional machines can be manufactured [1]. It also allows a straightforward approach from 3D CAD designs to the final products in a few simple steps allowing fast customization processes and easy modification [2]. Moreover, high initial costs as tooling, molding, dies, etc. are not required.

There exists several AM types including Fused Filament Fabrication (FFF) also known as Fused Deposition Modelling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), Laser Metal Deposition (LMD), Laminated Objective Manufacturing (LOM) and other different methods [3]. The mentioned methods might be chosen according to the type of material to be used, speed, machine cost, finishing quality or other aspects.

AM is used in several industries such as aerospace, automotive, biomedical any field that needs Rapid Prototyping such as architectural design representations or other fields [3]. Those industries are getting bigger every day and are manufacturing more products with AM. To illustrate, in 2015 the U.S. Food and Drug Administration (FDA) has accepted the first prescribed medicine produced with AM [4]. The growth in those areas generates the need for tracking parts. With the help of AM, each manufactured part can be embedded with some tracking information without additional manufacturing processes. With this application, companies would be able to get information directly from the part such as the fabrication date, the inspection records, the product number, etc. This method would also make the part changing processes faster since the part information would be obtained quickly in the case of failure. Those are especially important in automotive or aerospace fields, where safety is critical [5].

There are also other reasons for the need of information embedding on AM parts. AM allows a direct approach from CAD design to the final product [2]. On the other hand, conventional manufacturing processes require some personal skill and some specific materials such as dies or molds for embedding information. Since AM does not require high operator skill or complex equipment; anyone can fabricate parts if they have the design files. The fact that AM models are in digital environment and are easy to produce generates a serious risk of counterfeit parts. If a CAD file of an AM part is stolen, it would be simple to make copies of that part. Even though the look of the part may look as the original, it may use different settings, different materials and it may not have the necessary standards or quality control procedures. If such parts are circulated in the market, it may cause some serious risks depending on the industry [6]. It should be noted that even in 1997, the cost of counterfeit parts in the automotive sector was 12 billion dollars [7]. Thus, this is a serious topic to consider. Other than these reasons, information embedding can also be used for tracking robots, toys and other daily products [8].

Compared to the conventional labeling approaches such as stickers and markers, embedding information using additive manufacturing offers more potential. Firstly, stickers are prone to scratch and can be unreadable after a period of time. Secondly, additive manufacturing offers more secret methods such as embedding information into the parts which conventional labeling approaches cannot fulfil.

This paper focuses on embedding information into a part using Mondrian patterns. Piet Mondrian is a Dutch artist famous for his creations which uses strict vertical/horizontal lines separated by contrast colors [9]. The style used by Mondrian is a widely used concept for architects to create different design patterns. This same pattern is utilized to develop a new coding approach like QR codes and tested on AM parts.

2. Material and methods

The pattern is tested with PLA (Polylactic acid) filaments using an FFF (Fused Filament Fabrication) type of 3D printer. Other AM methods can also be utilized for the same purpose.

It was already mentioned that Mondrian patterns use strict vertical/horizontal lines separated by contrast colors [9]. These patterns can be imagined as a rectangular grid consisting of different colors. Since commercial 3D printers can only print in the original color of the filament, different colors are represented by different printing orientations. In order to generate these grids with different printing orientations, a script is developed using the CAD software Rhinoceros3D and the Grasshopper3D add-on, parametric design tool. Those patterns are generated according to a new coding system that we have developed. This code is given as an input to the script with other values such as the grid size and grid dimensions. The script outputs a Mondrian pattern surface as shown in Figure 1, which is then placed on the surface of the part. Once the part is manufactured, the final step is to read the code from that part using an image processing software developed using Python language and the OpenCV library.

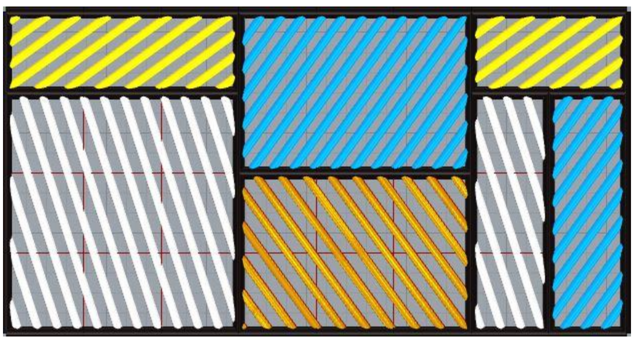

Fig 1. Example output of Grasshopper3D.

2.1 Coding

The proposed approach uses a simple algorithm which can be altered or modified later. The pattern is divided into rectangular grids. Each grid has a specific printing orientation, and each orientation has a specific output. In this case, the coding language is created using a number system from *0* to *9*. Since the printing orientation varies from *0* to *180* degrees and the initial and final angles mentioned here are the same for an image processing software, the angles increase with *18* degrees increments starting from zero. This mapping is presented in Table 1.

Table 1. Outputs with respect to the printing orientations.

Orientation (°)	Output
0	0
18	1
36	2
54	3
72	4
90	5
108	6
126	7
144	8
162	9

2.1 Decoding

The algorithm advances row per row starting from the top row. In each row, it goes column by column starting from the left. There are two rules for the grid output to be printed. Those rules can also be shown mathematically, where $A_{i,j}$ represents the grid cell that is in the *ith* row of the *jth* column.

The first rule is the current grid being different from the grid in the same column of the next row, which can be represented as

$$A_{ij} \neq A_{(i+1),j}$$

The second rule is the current grid being different from the grid in the next column of the same row, which can be represented as

$$A_{ij} \neq A_{i,(j+1)}$$

If those two rules are satisfied, the grid output is printed. Otherwise, it is ignored. An example can be given from the grid given in Figure 2, which is the input of the output shown in Figure 1.

Here, one can observe that the cell $A_{1,1}$ does meet the first rule but does not meet the second rule. Thus, it is ignored. On the other hand, the cell $A_{1,3}$ is printed since it satisfies both rules.

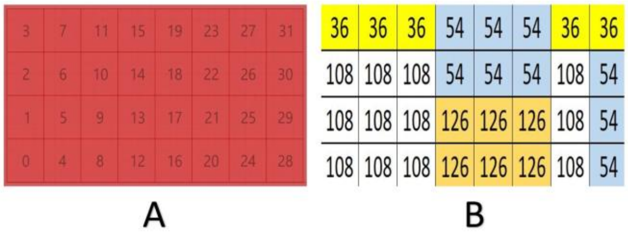

Fig 2. A) Grid in Grasshopper3D circuit, B) Representation of the grid.

3. Results and discussion

The output of the script is embedded on the surface of the part to be manufactured. The gap between the lines is increased to have a better observation of the printing orientation. The manufactured part can be seen in Figure 3, which has the pattern provided in previous figures.

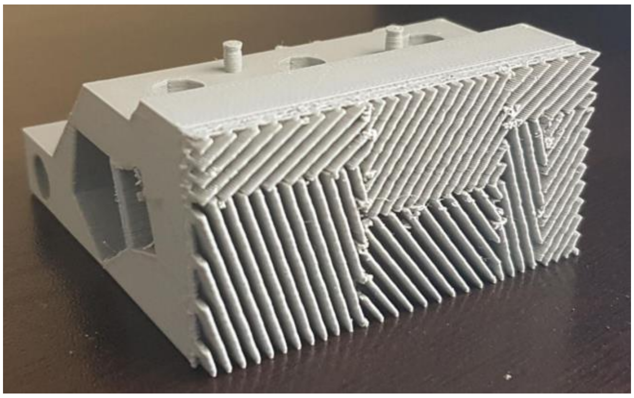

Fig 3. Manufactured part with the pattern used in previous figures.

The part shown in Figure 3 is scanned using the software developed. After the image of the surface is acquired, it is fed to the software and the output is obtained as a matrix. The code itself and the matrix on the provided image are shown in Figure 4. The output is as expected which proves that the code is working.

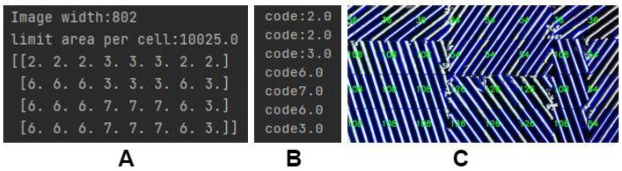

Fig 4. A) Matrix output B) Code output C) Image output.

The printing time would not be significantly affected. Recall that this method uses the best printing orientation and Figure 3 is showing the exaggerated features to present the working principle of this paper. In other words, the distance between the beads shown in Figure 3 would in reality look like the one shown in Figure 5 which is the default distancing in the slicer. This method would not require additional supports or printing time. On the other hand, it would require a part surface facing the printing bed. This constraint may affect the printing time and require use of supports depending on the part geometry.

Fig 5. Default distances between the beads for different printing angles that are used in the paper.

4. Conclusions

The method proposed in the paper bridges arts and technology to embed information onto the surfaces of AM parts. Although the method has not been tested a lot and is rather new, the results have shown that it is working.

A lot of additions and modifications can be done to improve the process. The pattern generation script can output a direct G-code instead of a CAD file for 3D printing. The image scanning software can be improved to reduce the dependence on the lighting of the room and the color of the filament. Other tools such as surface roughness measuring devices can also be used to reduce this dependence. With such devices, the pattern can also be made smaller so that it cannot be noticed clearly with naked eye. The algorithm can be changed. This has endless possibilities which gives this system a potential to be used in areas that require security.

This method can be combined with other methods and manufacturing processes such as scanning with terahertz region [8] or x-ray scanning [10] where it would be possible to hide the pattern into the part. Such an approach would increase the invisibility of the code and also allow the usage of different types of materials compared to the ones used in FFF.

There may be different usage areas for this implementation. Some people might prefer it to hide information whereas other people can simply use it because of the aesthetic appeal of the method.

To conclude, this work shows the implementation of Mondrian style patterns to embed information on parts. This feature can be combined with previous works in the same field and can also be an alternative to the widely used QR codes. This method offers a lot of flexibility and potential that can be developed to create very complex patterns and algorithms that are very difficult to decipher.

Author's statement

Authors state no conflict of interest.

References

1. J. Savolainen and M. Collan, "How Additive Manufacturing Technology Changes Business Models? – Review of Literature," *Additive Manufacturing*, vol. 32, p. 101070, Mar. 2020, doi: 10.1016/j.addma.2020.101070.
2. R. Jiang, R. Kleer, and F. T. Piller, "Predicting the future of additive manufacturing: A Delphi study on economic and

societal implications of 3D printing for 2030," *Technological Forecasting and Social Change*, vol. 117, pp. 84–97, Apr. 2017, doi: 10.1016/j.techfore.2017.01.006.

3. N. Guo and M. C. Leu, "Additive manufacturing: technology, applications and research needs," *Front. Mech. Eng.*, vol. 8, no. 3, pp. 215–243, Sep. 2013, doi: 10.1007/s11465-013-0248-8.
4. "Aprecia Pharmaceuticals, FDA approves the first 3d printed drug product." 2015. [Online]. Available: https://www.aprecia.com/news/fda-approves-the-first-3d-printed-drug-product
5. R. Kikuchi, S. Yoshikawa, P. K. Jayaraman, J. Zheng, and T. Maekawa, "Embedding QR codes onto B-spline surfaces for 3D printing," *Computer-Aided Design*, vol. 102, pp. 215–223, Sep. 2018, doi: 10.1016/j.cad.2018.04.025.
6. F. Chen, Y. Luo, N. G. Tsoutsos, M. Maniatakos, K. Shahin, and N. Gupta, "Embedding Tracking Codes in Additive Manufactured Parts for Product Authentication," *Adv. Eng. Mater.*, vol. 21, no. 4, p. 1800495, Apr. 2019, doi: 10.1002/adem.201800495.
7. D. G. Aliaga and M. J. Atallah, "Genuinity Signatures: Designing Signatures for Verifying 3D Object Genuinity," *Computer Graphics Forum*, vol. 28, no. 2, pp. 437–446, Apr. 2009, doi: 10.1111/j.1467-8659.2009.01383.x.
8. K. D. D. Willis and A. D. Wilson, "InfraStructs: fabricating information inside physical objects for imaging in the terahertz region," *ACM Trans. Graph.*, vol. 32, no. 4, pp. 1–10, Jul. 2013, doi: 10.1145/2461912.2461936.
9. P. D. Stokes, "Creativity from Constraints: What can we learn from Motherwell? from Modrian? from Klee?," *The Journal of Creative Behavior*, vol. 42, no. 4, pp. 223–236, Dec. 2008, doi: 10.1002/j.2162-6057.2008.tb01297.x.
10. C. Wei, Z. Sun, Y. Huang, and L. Li, "Embedding anti-counterfeiting features in metallic components via multiple material additive manufacturing," *Additive Manufacturing*, vol. 24, pp. 1–12, Dec. 2018, doi: 10.1016/j.addma.2018.09.003.