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Embedding QR Codes on the Interior Surfaces of FFF Fabricated Parts

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Abstract

Quick Response (QR) codes have been utilized in various fields of manufacturing after their introduction to the automotive industry. Due to their error correction algorithms, they have advantages over the other coding schemes. Various information regarding the parts can be stored into these QR codes, which are conventionally printed on the labels of the artifacts. In this study, we propose an automated approach for embedding QR codes on the interior flat surfaces of 3D printed artifacts. Since we are using the interior surfaces, the outer surface or the shape of the object is not affected by the QR code patterns. We used Rhinoceros3D (CAD software) and Grasshopper3D (analytical modeling tool for Rhinoceros3D) environments for the realization of the proposed method. We fabricated several parts with QR codes in them utilizing a Fused Filament Fabrication type of 3D printer and showed that the codes are readable via the cameras of the mobile phones. We concluded the paper with proposing some application areas of the method.

Keywords: QR Code; Additive Manufacturing; 3D Printing; Fused Filament Fabrication

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1. Introduction

This study concentrates on embedding Quick Response (QR) codes on the interior surfaces of the 3D printed artifacts. QR code is a 2-dimensional (2D) coding system developed by Denso Wave. It utilizes the Reed-Solomon codes which are powerful linear error correction codes [1]. The content of QR codes can be any kind of text, website address, video link, etc. A QR code reader can easily read the code using the images acquired via different means and then takes some actions depending on the content of the data decoded. For instance, if the code represents the address of a webpage, it asks to open the corresponding page in the web browser.

The importance of 3D printing, in other words, Additive Manufacturing (AM) is increasing day by day with the technological developments in various fields. Fused Filament Fabrication (FFF) technology, known as the most widely used AM method in the world, is estimated to be the technology used by nearly 70 % of the world's 3D printers [2]. In this study, FFF type of a 3D printer is utilized to embed the codes on the surfaces of the objects. In the majority of previous works, QR codes were fabricated with a different color than the original color of the products to obtain color contrast for better scanning. There are also QR codes printed with a single color, which can be read with the help of the light differences. In these approaches, shadows become the second color which improves scanning [3]. Moreover, some researchers were able to implement these methods with different types of material, such as acrylonitrile butadiene styrene (ABS) for FFF, photopolymer resin for inkjet and aluminium alloy for selective laser sintering [4].

In the proposed approach, the code is hidden inside the part and it can only be read with the help of a light source. Outer surfaces of the artifact are not affected by the embedded QR code. However, there are certain limitations of the method, such as the requirement of uniform background light and the proper layer thickness underneath the QR code. The steps of integrating the QR code on the 3D printed parts include generating the QR code representing the information, generation of the CAD model, and embedding the CAD model of the QR code on the appropriate surface of the artifact. Once the conventional design and fabrication pipeline of 3D printers is followed, QR codes embedded on the interior surfaces would be lost. That’s why we developed an automated approach utilizing algorithmic tools for CAD software.

Regarding the implementation, Rhinoceros3D and Grasshopper3D software are used for the automated processing of these steps. The process and the inputs that the user has to provide are described in the relevant fields. The paper offers a new concept for embedding the invisible QR codes inside the artifacts. Practicability of the approach is discussed in the following sections of the paper.

2. Related work

QR codes have many advantages over the traditional codes. These are large storage capacity, fast scanning and response, high error correction rate, 360-degree readability, scannable with very small print sizes, and support in many languages [5]. Thanks to all these advantages, it is of great importance in many areas nowadays, and its usage area is growing continuously. One of the application areas of QR codes is the pharmacy. The drug printed with the FFF technology was released a few years ago by Fitzgerald [6]. Such drugs with embedded QR codes could be advantageous for the people who miss the prospectus and forget the proper dose of the medicine. People can just scan the QR code with their mobile phones and get all the information and warnings regarding the drug.

In addition, QR code printing is done with a 3D printer on the parts to distinguish the fake products from the original ones. For instance, Chen et al. [4] used the 3D printing process, which includes inkjet and selective laser sintering in addition to the FFF, to explode the QR codes with the help of CAD software in order to present dummy QR codes to scanning devices. Thus, someone who doesn't know how to look at the right place can find the correct QR code. Although, the QR Code produced by inkjet and selective laser sintering methods can be seen, it is not scannable conveniently without making any contrast settings. Regarding these methods, QR codes cannot be hidden completely due to the fundamentals of the technologies.

Unlike 2D QR codes embedded on a planar surface, Kikuchi et al. [3] have introduced a different approach for embedding the codes on freeform surfaces indicated by B-splines. In this approach, the clarity of the QR code appears with the shading of the channels without the need of multi-colors. In addition, 2D QR code can be obtained at certain depths according to the shape of the surface. However, this method is not suitable for materials that are too dark or too bright, and in highly bright and dark environments because of the difficulty of shade grooves. The major advantage of this approach is to embed the 2D QR codes directly on non-linear surfaces so that the code can be read from a right angle as a two-dimensional code.

Surface fitting is an important issue for embedding QR codes into the B-spline surfaces. Common usage of B-splines is increased dramatically after the mesh transformation process is considered as time-consuming [7]. Mesh transformation is replaced with isogeometric analysis which uses B-splines to represent linear basis functions. The B-spline method also creates some difficulty in modeling beside providing an advantage on the analysis of solid parts. Researchers try to handle these difficulties of modeling with surface fitting by iterating geometry with interpolation or approximation approaches. In the approximation method, B-spline passes close to the exact data points [8]. Interpolation is a better approach since it uses exact data points for fitting the surface. While using the exact data points, one reference point is selected and the remaining ones are placed as the foot points from the reference point [9].

The AMF (Additive Manufacturing Format) format which is documented by ASTM [10], expresses smooth geometries using curved triangles. On the other hand, Paul and Anand [11] stated that while slicing the parts, curved triangles of the AMF are repeatedly subdivided into planar triangles, and this may result in approximation errors in the STL file format. Sasaki et al. [12] introduced an outline for giving the shape of heterogeneous bodies in terms of B-spline functions and a technique for slicing them directly for AM. The most important contributions of this study are that a fast-volumetric property data fitting in terms of B-spline functions and a direct slicing technique for passing the path of the tools owing to all the feature points of the heterogeneous body within the slicing plane. Thus, the B-spline curves, volume and the related feature data are sliced directly without converting the STL format and losing the topological and geometric stability of the original shape.

3. Overview of the proposed method

There are many phases to be completed for embedding the QR codes. The procedure starts with generating the raw QR code. At this point, the decision about the negativity of the code should be made. QR code scanners utilize the differences between the black and white regions. Although a high contrast ratio is useful for scanning the QR code, this general knowledge might not indicate that QR codes are not allowed to use other color combinations. The key point is that the code must be darker than the background. On the contrary, a small amount of the scanners succeed to read the code while the background is darker [13]. As far as contrast difference is adequate, negative of the QR code with lighting from the background can be scanned.

Making 3D QR code comes after generating the code itself. The sufficient depth of the code should be determined. The way of that, optimum depth must provide adequate obscuration to the coded part. Additional requirement of the optimum depth is that the strength of the part shouldn't be decreased. Only the depth height should be optimized to provide shadows.

Moving the QR code onto the desired surface is done with the help of the normal vector of the surface. For that purpose, the solid part is first divided into surfaces. Secondly, the point, which is given as input by the user, is checked whether it is on the desired a surface or not. After the point and the corresponding face is detected, the 3D QR code is moved to the given point. The depth of the QR code is fitted parallel to the normal vector of the desired surface. Finally, the exact location of the QR Code on the surface is decided and the code is scaled.

Embedding the QR Code into the surface is finalized with the help of solid subtraction. The contrast difference of the curved surfaces could be prevented from offsetting the surface splines into the solid part. Finishing with a thin layer results in better aesthetic appearance. An additional benefit of the finish layer is that the code is scannable only when the background is lighted. The QR code is not noticed and scanned without any background light. However, the layer below the area where the QR Code is embedded has to be thin so that it can pass the light sufficiently. Another important point is that the negative QR code must be removed from the geometry since the QR Code can be read from the light given below as shown in Figure 1.

In Figure 2, the overall process is given. From the starting point, the method requires three essential inputs which are text input, error correction factor of the QR code and input geometry. 2D QR code is generated based on the received text and the error correction percentage. The important point here is that the error should not exceed 30 % in order not to affect the readability of the QR code. The input geometry represents the shape where the QR code is to be embedded. Then, the solid difference is performed by moving the QR code to the desired location on the corresponding surface of the geometry. Thus, the final geometry is obtained by embedding the QR code at a certain depth on the surface. Additionally, for a concept in which the QR code can be read with the help of the subtraction of negative code and the light from below, a few more steps are required after the solid subtraction, such as a thin layer on top of the QR code and an adequate space below the 3D QR code where the uniform light source can enter. Then, the type of final geometry to export is determined by the user.

Fig. 1. Scanning the QR code with a background light.

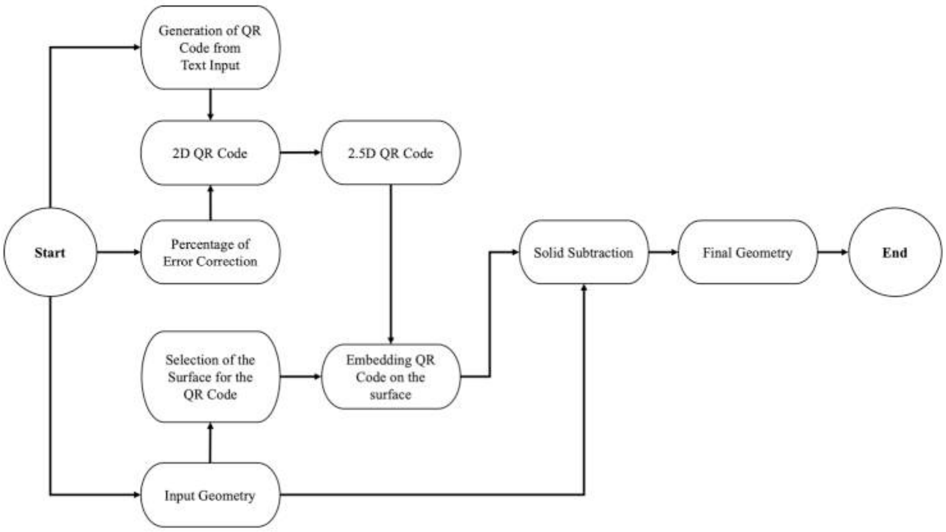

Fig. 2. Pipeline of the proposed method.

4. Experiments and results

The early stage of our studies and experiments have focused on the possibility of QR code reading with shading, or lighting and creating color differences without using multi-colors. In these experiments, the 2-dimensional QR code were converted to 3D codes (Figure 3) with the help of a script written via Python programming language. It provides extruded negative version of the code, which is the reverse of the original QR code.

Figure 4 shows the negative QR code to be embedded in the artifact by grooving. The remaining parts in the pit can easily be read as the QR code in a bright environment with shading. The interesting part in these experiments is that when uniform light source is applied under the negative code, the QR code shown on the right picture can be read with QR code scanner. This means that when enough color differences are obtained, the QR code can be scanned regardless of the light and the color. However, instead of creating the color differences shown in Figure 4a, which is quite difficult to read, it is easier to read when the negative of the picture is taken with a simple application shown in Figure 4b.

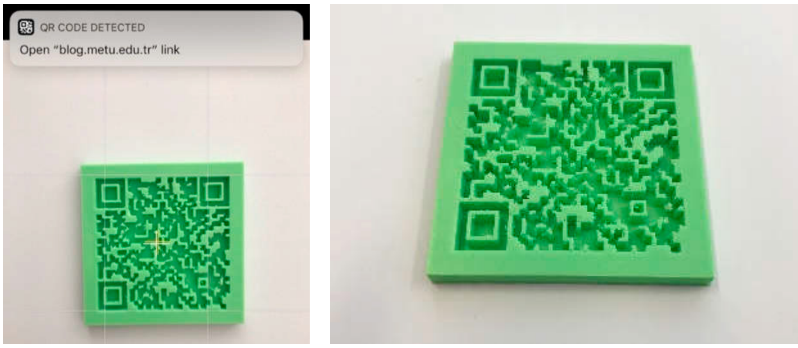

Fig. 3. Initial trials of 3D printing and scanning of QR codes.

a **b**

Fig. 4. Initial trials of scanning QR code with a background light

After the success of the initial trials, we focused on the automation of all these steps using Rhinoceros3D and Grasshopper3D software. The steps are summarized as below.

Step 1: Generating the 2D QR code

Step 2: Converting the 2D QR code into 2.5D solid

Step 3: Placing the solid QR code onto the desired surface

Step 4: Subtraction of 2.5D QR code

Step 5: Embedding the thin layer onto the surface with the QR Code

An example part in the shape of a pyramid is modified with the automated approach is provided in Figure 5. The QR code is embedded on the bottom surface of the part and the code is scanned via lightening the pyramid from the outside. As can be seen the outer shape of the part is not modified. When it is not enlightened, the QR code cannot be seen. Our method can also be employed on the outer surfaces of the artifacts as seen in Figure 6. Regardless of the complexity of the surface, the QR codes are scannable.

Fig. 5. Scanning of the QR Code embedded into the solid.

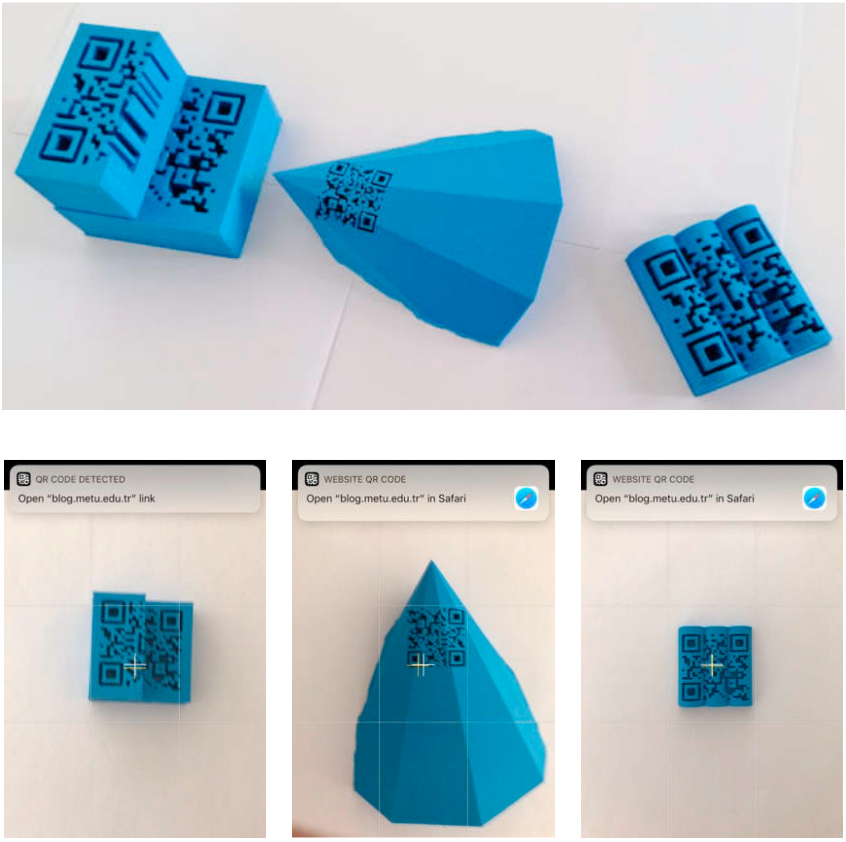

Fig. 6. Further examples.

5. Conclusions

Our study has indicated that embedding any information with the help of the 3D QR Code, such as embedding into the solid part with a thin layer offset from the surface, can be handled successfully. The capability of FFF technology prevents us from the requirement of post-processing. In addition, the shadow approach clears up the doubt about contrast and readability of the QR codes. Multi-color 3D printers are not required for fabrication. According to the test cases we fabricated, the 3D QR Code could be used successfully with sufficient depth adjustments to ensure a binary code and make it readable with the help of the backlight. The approach with scanning via the background light has some limitations. It requires a thin layer at the corresponding surface and uniform background light. When the parameters are set correctly and the QR code is employed on the areas that do not require much support, these problems can easily be eliminated. Another problem is about exporting the final geometry as an STL file since it is not suitable for storing information related to the interiors of the artifacts. As a future work, instead of saving the final part in the form of an STL file, direct slicing with Rhinoceros3D and Grasshopper3D will improve the overall fabrication, surface quality and scannability of the QR codes. Additionally, direct slicing gives the advantage to produce more freeform and complex geometries and it also overcomes the problems of using multi-material structures, process precision, and ease of file management [14].

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