Laser Polishing: A Postprocessing Protocol for Fused Deposition Modeling 3D Printed Parts Using Existing Tooling

Emilio Latorre
elatorre@bu.edu
Computer Science, Boston University
Boston, Massachusetts, USA

Emily Whiting
whiting@bu.edu
Computer Science, Boston University
Boston, Massachusetts, USA

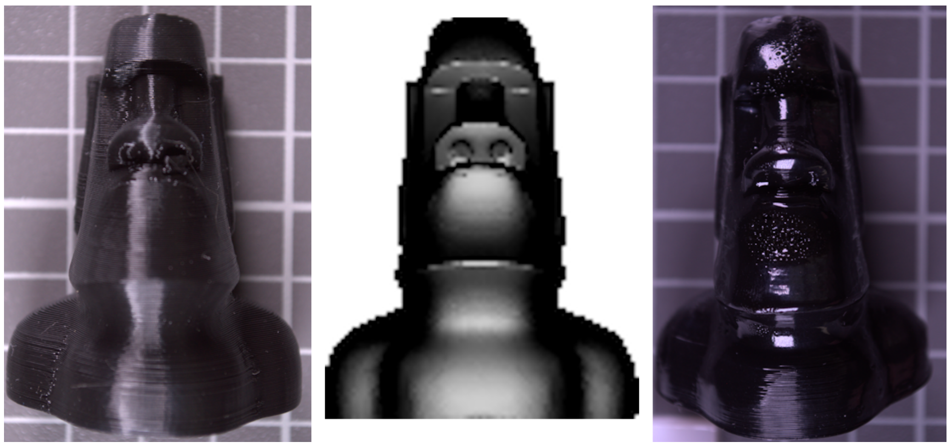

Figure 1: (Left) Original 3D printed Moai statue. (Center) Cubic normal map. (Right) Result polished according to our protocol.

ABSTRACT

3D printed objects produced by fused deposition modeling have functionally and aesthetically unpleasing surfaces due to factors inherent to the process. Although it is possible to reduce the resolution of these artifacts during printing, it is not possible to eliminate them entirely, and thus postprocessing will be required to achieve a smooth surface finish. Many methods of postprocessing require a large amount of time and labor or chemical solvents. Using an unmodified laser cutter as a source of heat, we are able to achieve a great improvement in surface finish with minimal warping and fast cycle time. We propose laser polishing as a method that is simple, safe, low-cost, and uses readily available equipment.

KEYWORDS

Additive manufacturing, surface polishing, fused deposition modeling, laser cutter, surface finish

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1 INTRODUCTION

Surface finish of FDM 3D printed objects and how to improve it has been a question of much interest in computational fabrication. With regard to surface finish, FDM leaves much to be desired compared to other methods of printing, with objects having visible extrusion lines and layer staircase effect.

We propose a new procedure for using heat from laser engraving to improve surface finish. Smoothing is achieved by locally melting the surface using an unmodified commercial laser cutter. The micrographs in Figure 2 illustrate the effect of polishing.

1.1 Related Work

There is substantial work on improving surface quality of 3D printed objects, by adapting the layer height [Pandey et al. 2003; Tyberg and Bøhn 1999], improved slicing techniques [Alexa et al. 2017; Etienne et al. 2019; Wang et al. 2015], clever part orientation [Masood and Rattanawong 2002; Zhang et al. 2015], or decomposition into parts [Hu et al. 2014; Wang et al. 2016]. However, these do not eliminate the texture of layers and extrusion lines. Thus, some level of post-processing will be required. Options include abrasives, chemical solvents, and heat. Abrasive methods are labor-intensive and produce dust and other mess. Solvents pose safety challenges [Preez et al. 2018], and are specific to compatible polymers, for example Acetone Vapor Polishing for ABS parts [Colpani et al. 2019].

Our focus is on heat as a processing method. Ironing during the print, using the nozzle as a source of heat, has been attempted with relative success [Sardinha et al. 2021], but is limited in the geometries it can work with. Laser polishing 3D prints has been explored in prior work [Braun et al. 2020; Chai et al. 2018; Chen and

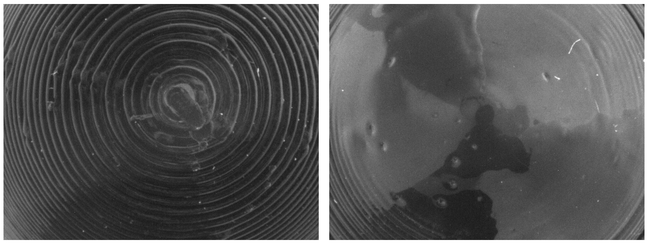

Figure 2: Micrograph of the surface of unpolished (left) and polished (right) 3D printed hemisphere.

Zhang 2019; Dewey and Ulutan 2017]. Braun et al.[2020] show laser polishing to be a highly effective method of postprocessing, achieving very low surface roughness. However, their experimental setup involved the creation of a dedicated polishing machine incorporating a sensor feedback loop in its control and a 200W laser, which poses logitstical and safety challenges for most environments. Chai et al. [2018] use an industrial 40W machine, but their investigation is limited to flat constant-thickness samples in order to conduct detailed analyses of the surface profile. In contrast, we present an end-to-end approach for processing fully 3D freeform geometries using an unmodified laser cutter.

2 METHOD

2.1 Overview

In order to evenly polish the surface, we use the bitmap engraving function of the laser cutter, inputting a map of the normal of the surface of the object. The following is an overview of our process:

(1) 3D print object.
(2) Generate normal map and import in laser cutter.
(3) Size and locate bitmap to correspond to object dimensions.
(4) Locate object in laser cutter to align with bitmap.
(5) Run laser cutter on object using engraving settings.
(6) Repeat steps (2)-(5) for additional orientations as needed.

2.2 Surface Normal Mapping

Our laser polishing approach uses the bitmap engraving function of the laser cutter. We input a map of the normal of the surface of the object. Surface normal direction is important, because the laser is most efficient and powerful when angled perpendicular to the surface of the object to be polished. To generate this normal map, we created a program that imports the STL file used to print the object to produce the map.

The following function was used to convert the normal angles of the object surface to bitmap pixel brightness, p:

$$p = \max(0, (255 * (\mathbf{n} \cdot \mathbf{u})^3) - \alpha) \tag{1}$$

where $\mathbf{n}$ is the unit surface normal intersecting the laser within that pixel, and $\mathbf{u}$ is a unit vector in the direction of the laser beam. Scalar α is an adjustment factor to ensure the entire surface of the object will be polished (α was set to 50 for all trials). The mapping function was determined experimentally using hemispheres as a calibration shape.

2.3 Implementation

All experiments were conducted using unmodified 60W and 80W laser cutters. All objects were printed in PLA with a 0.4mm nozzle and 0.2mm layer height. The objects are supported in different orientations by a set of negative-cavity "mold" blocks

Our application uses the same STL used to print the object to generate the map, meaning that no additional preprocessing is required. Our normal mapping application was written in Java and produces maps in BMP format. Models were sourced from https://www.thingiverse.com/.

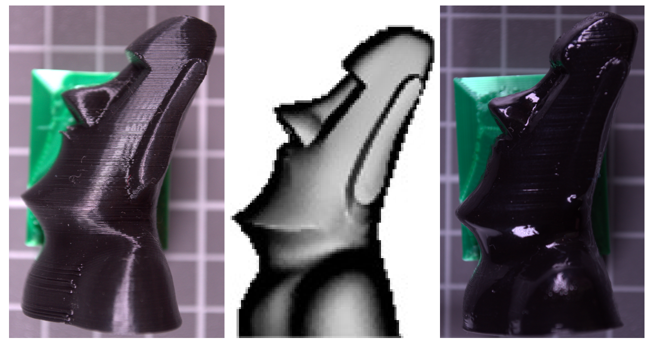

Figure 3: Moai statue with side orientation. (Left) before polishing; (center) normal map; (right) after polishing.

3 RESULTS & CONCLUSION

Our laser polishing approach was successful at providing a smoother finish on 3D printed objects. We were able to polish nearly the entire surface on a range of sample objects with freeform 3D geometry. The images in Figs. 1, 3, and 4 show the results of polishing on different objects printed in different colors of filament.

While the smoothing is significant, it does not completely eliminate the extrusion and layer artifacts in objects. Additionally, in some areas the objects display some bubbling artifacts. Some sharper details can be damaged during the polishing process, as observed in Fig. 4.

Figure 4: Bas-relief plaque before (left) and after (right) polishing, showing limitations in loss of detail.

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