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EXPLORING THE VERSATILITY OF OPEN-SOURCE SOFTWARE FOR INDUSTRIAL IMAGE PROCESSING: A CASE STUDY

Martin Necpal , Marek Vozár , Jozef Peterka
University of Slovak University of Technology in Bratislava, Faculty of Material Sciences and Technology in Trnava, Trnava, Slovakia

Abstract: *The article investigates the potential applications of free open-source software in image processing for a diverse range of industrial uses, including laser texturing, machining, and additive manufacturing. A case study is presented, wherein digital photography is utilized to capture a scene, followed by processing in the GNU Image Manipulation Program. The processed image in the form of a height map is then imported into the Blender software suite to generate a high-resolution 3D model. The quality of this model is further enhanced using various software functions such as object modifiers, and mesh sculpting. Based on the high-quality 3D model, a high-resolution height map is rendered. Subsequently, the exported height map is utilized for surface modification through laser beam technology and additive manufacturing via fused deposition modeling. This analysis aims to investigate the efficacy and adaptability of open-source software in industrial settings. The article also highlights the steps involved in: 1) capturing an image digitally through photography, 2) creating a 3D artistic relief in Blender, 3) converting the polygonal model of the relief for laser micromachining graphics, and 4) adapting the polygonal model for 3D printing graphics. The study concludes with an evaluation of the results, examining the suitability of use of open-source software for generating relief from photographs for various industrial applications.*

Key words: 3D relief, 3D printing, Laser micromachining, Blender software

1. INTRODUCTION

Utilization of 3D models for manufacturing processes has been a technical method of choice in the past decades, and at present it still remains a highly relevant approach (Chlebus & Krot, 2016). Currently, there are multiple different ways of obtaining a three-dimensional model such as parametric or box modeling, sculpting, or optical scanning (Rusinkiewicz et al, 2002; Pollefeys, 2004). Case use of these methods depends on many factors and also the limitations of each method (Vranic & Saupe, 2004). In general, entry data containing information such as dimensions, surface characteristics, or constraints are needed to begin the creation of the model (Rivers et al, 2010). The practice of using visual cues to sketch the base model and then continue further with its refinement can often be a viable solution, especially if the source material is of poor quality or a highly detailed and precise model is needed for the application (Remondino & El-Hakim, 2006; Chen et al, 2003). This is especially important for high-precision industrial manufacturing methods such as laser beam machining. However, in some cases using a highly detailed model can be an issue due to drawbacks when it comes to computation time resulting from a high number of polygons requiring processing as well as large file size (Bernardini & Rushmeier, 2002). Therefore, adequately adapting both the source images and the final model is a much-needed step in the preparation for the subsequent manufacturing process, as it can significantly influence the resulting quality an accuracy.

This article examines the innovative application of Blender, a highly advanced and robust open-source software tool specifically engineered for the complex creation and editing of three-dimensional data, which can also facilitate the development of reliefs derived from images captured digitally via a camera. Following this preliminary phase, the prepared relief is subsequently utilized to generate the precise CNC paths that are implemented for laser micromachining and additive manufacturing processes. Thereafter, this generated data is employed in the fabrication of samples to evaluate the appropriateness of the constructed three-dimensional relief.

2. MATERIALS AND METHODS

2.1 Source image processing

An uncompressed photograph in the .ARW format was captured with a digital camera to ensure sufficient clarity for further editing. Parameters with which the photograph was taken are following: 1/1250 exposure, focal length of 28 mm and ISO of 100. The file was loaded in the GNU image manipulation software, where it was desaturated and separated into layers depending on the image depth and perspective. Layers were then overlayed with black and white color gradients to produce an initial height map with a resolution of 6048 x 6048 pixels. Figure 1 shows initial layer separation of the grayscale photograph.

Figure 1: Initial layer separation of the grayscale image

2.2 3D model preparation

Following the initial manual editing, the height map was loaded in the Blender software. A simple plane object which was subdivided 10 times was added to the scene. Subdivision surface object modifier with the setting of simple algorithm and six levels of subdivision was applied to produce a mesh with a high enough polygon count, to ensure matching texel density with the pixels on the height map. Another object modifier was used to produce displacement of the subdivided plane, into which the texture with the height map was linked. While the height map was of sufficient resolution, the 3D object generated with it was still lacking features that would produce the desired result. In order to continue with further editing in the sculpt mode, all the object modifiers were applied, and the subdivided plane was turned into a 3D object. Prominent visual features from the original photo were hand-drawn using multiple brushes in the sculpt mode and some artifacts from the height map were smoothed. Additionally, a simple text object was inserted into the scene as well. Figure 2 shows final 3D model. Total polycount of the model was more than 10 million triangles.

Figure 2: Final 3D model

2.3 Height map rendering

After the 3D model was finished, it needed to be turned into a higher resolution depth map in order to be used for the laser micromachining. A simple node setup in the Cycles rendering engine was used to transfer the mesh into a depth map. Render settings were following – resolution of 8128 x 4096 pixels, 16-bit color depth and no compression. Adjustment of the gamma value was required to achieve full grayscale range that could be utilized for laser micromachining software. Figure 3 shows height map render setup in Blender application.

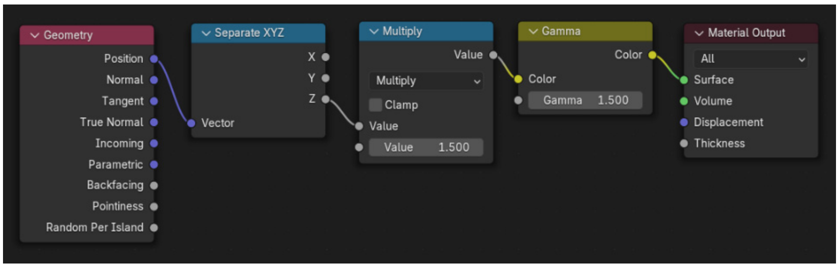

Figure 3: Height map render setup

Figure 4 shows final render of the 3D model as a height map, which was then imported into the software for laser micromachining.

Figure 4: Rendered height map

2.4 Laser micromachining

The 3D relief model was initially produced using laser micromachining on a stainless steel plate. The production process and program generation for the machine require a BMP map as the template. From this BMP map, layers are generated, and the material is subsequently removed by the laser. In the case of the white layer (represented by a pixel value of 0), the laser does not pass over the surface, while for the black layer (represented by a pixel value of 255), the laser passes over the surface multiple times, penetrating deeper into the material and forming the 3D relief. A critical factor for successful laser micromachining is the accurate setting of machining and laser beam parameters. To determine the optimal parameters, experimental methods and statistical models are utilized, as outlined in the literature (Šugár et al, 2018; Kuruc et al, 2015), which employed the same machine used for our relief fabrication. The machine parameters in this process were as follows: laser beam power of 65 W, frequency of 80 kHz, scanning speed (i.e., beam movement speed) of 1800 mm.s^{-1}, and a path spacing of 10 µm. These settings corresponded to a material removal rate of 2 µm per layer. With 255 layers being removed, the maximum depth of the relief was calculated as 255 layers × 2 µm = 510 µm, approximately 0.5 mm.

The Figure 5 shows the generated paths to be used for laser machining and the solid colors correspond to the different relief layers. Each color represents a distinct layer, illustrating the intricate process of laser micromachining. The visual representation emphasizes the substantial number of generated trajectories, with the spacing between each trajectory set at a mere 10 micrometers. This close proximity results in a densely packed network of paths, highlighting the precision of the laser machining process. The multitude of trajectories indicates a meticulous approach to material removal, where each pass of the laser is finely tuned to achieve the desired depth and detail. The high frequency of these paths not only contributes to the overall complexity of the relief but also reflects the advanced capabilities of the laser technology employed. As the laser moves across the surface, the layering effect becomes apparent, with each trajectory contributing to the gradual buildup of the final 3D form. The figure effectively captures the essence of the laser micromachining process, showcasing how the narrow distance between trajectories allows for the creation of intricate details and textures within the relief. This dense layering is crucial for achieving the desired depth and fidelity in the final product.

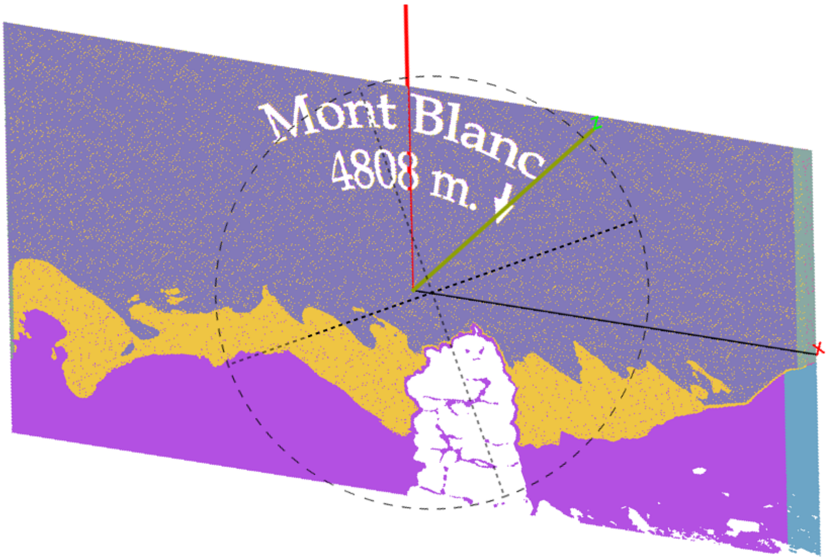

Figure 5: Generated paths for laser micromachining

2.2 3D printing

The 3D printing of the relief was carried out using a MARKETBOOT Replicator 2x, a non-professional standard FDM printer. Standard PLA was selected as the material due to its suitability for single-layer printing and its cost-effectiveness. The printing process followed the recommendations provided by the 3D filament manufacturer. The layer height was set at 0.2mm. The print speed was adjusted to 60 mm/s to ensure a balance between quality and efficiency, while the nozzle temperature was maintained at 210°C to achieve optimal adhesion and flow of the filament. After the initial print, a thorough inspection was conducted to identify any imperfections or areas that required post-processing.
The Figure 6 illustrates the process of generating layers in a 3D relief model during the additive manufacturing stage. It visually represents how the relief is constructed layer by layer, showcasing the incremental buildup of material. The figure may also highlight the specific parameters used, such as layer height and material type, emphasizing the precision and detail involved in creating the final printed part. Overall, it effectively conveys the methodical approach to layering in 3D printing.

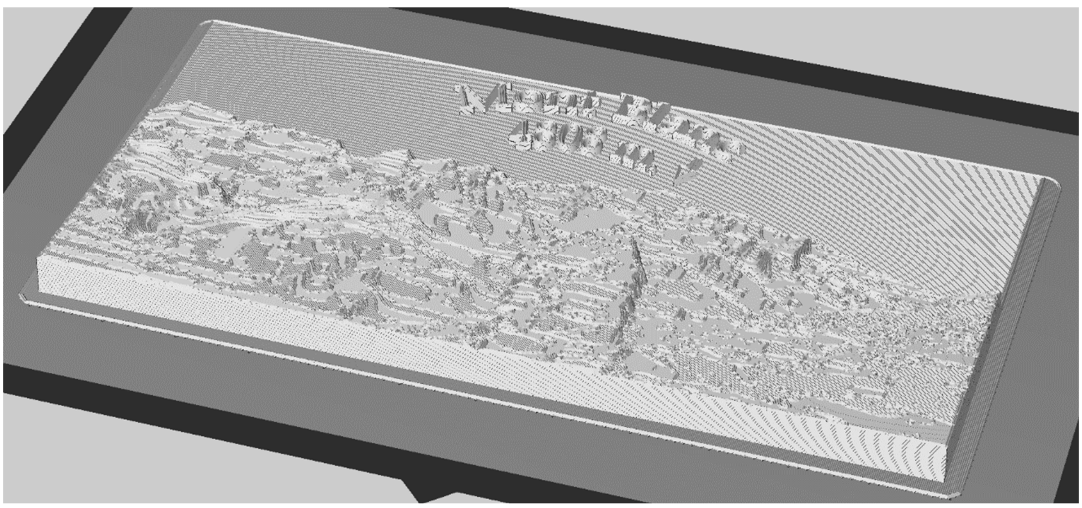

Figure 6: Generated layers in MakerBot slicer application

3. RESULTS AND DISCUSSIONS

3.1 Result of laser micromachining

The result of the laser machined part demonstrated a successful retention of small-scale visual details from the original photograph. However, the overall perceived depth of the relief was somewhat limited, which is expected due to the differences between the two-dimensional height map representation and the physical depth achieved through laser micromachining. Despite this limitation, the process effectively translated the digital model into a tangible relief, showcasing the capabilities of laser micromachining technology in preserving intricate details. This limitation highlights the challenges faced in translating complex designs into tangible forms, where the nuances of light and shadow play a crucial role in depth perception. Further refinement of the machining parameters could enhance the depth effect, allowing for a more pronounced three-dimensional appearance that better captures the original photograph's essence. Figure 7 shows a photograph of a laser machined sample of a complete 3D relief. It can be seen that there remain parts of the material unaffected by the laser beam, which is due to the high sensitivity of the software for color profile of the depth map. Having set too high cutoff for the white color resulted in the affected machined surface being incomplete. This error underlines the importance of adjusting the black and white levels of the imported height map in order to produce desired result.

Figure 7: Result of laser micromachining

3.2 Result of 3D printing

The 3D printing of the relief using the MARKETBOOT Replicator 2x resulted in a model that fell short of perfection. The printed output exhibited noticeable limitations in both quality and depth, impacting its overall appearance. To address these shortcomings, it is crucial to investigate and optimize the 3D printing process parameters. Adjustments in temperature, speed, and material could enhance the final product's detail retention. Additionally, reconsidering the design of the relief itself may also contribute to improved results. By refining both the printing techniques and the relief design, there is potential for a more visually appealing and detailed outcome. This dual approach could significantly elevate the quality of future 3D relief productions. Ultimately, striving for these improvements is essential for achieving better print results. The figure 8 shows a 3D printed relief created from PLA plastic material, showcasing noticeable imperfections that highlight the limitations of the printing process. The surface of the model reveals distinct layering, characteristic of Fused Deposition Modeling (FDM) technology, where each layer is visibly stacked upon the previous one. The visibility of the layers is pronounced, with each horizontal line marking the transition between layers clearly discernible. This results in a lack of fine detail, as the intricacies of the original design are lost in the pronounced ridges and valleys formed by the layering process. Additionally, the edges of the relief appear less crisp, further emphasizing the low-quality output. The overall appearance is somewhat blocky and lacks the desired depth. This is in part the result of the need to simplify the mesh density of the 3D model, since the 3D printer slicer software had issues processing the high polygon density of the sculpted model.

Figure 8: Result of 3D printing

4. CONCLUSIONS

The conclusion highlights the successful translation of the digital model into tangible 3D relief using Blender free software, sophisticated image processing and 3D modelling. Laser micromachining technology demonstrates the ability to preserve the intricate details derived from the original photograph. While the results demonstrate the effectiveness of the process, they also reveal significant limitations in the depth and quality of the 3D printed relief. The perceived depth of the relief, while retaining small visual details, was somewhat limited. Factors such as temperature, printing speed and material selection play a significant role in determining the quality of the final product and the retention of detail. By conducting systematic experiments to fine tune these variables, it may be possible to achieve a finer and more accurate representation of the intended design. In addition, a thorough rethinking of the relief design itself could yield improvements in visual appeal and detail, ensuring that the final product is more in keeping with the artist's or designer's vision.

Optimizing 3D printing parameters and reevaluating the relief design is important to improve future results. In conclusion, while the study successfully demonstrates the viability of using open source software to generate high quality industrial applications, it also highlights the need for continuous improvement and optimization. By addressing the identified limitations and taking advantage of technological advances, future projects can achieve a higher level of accuracy and artistry in the production of 3D reliefs. This constant pursuit of excellence not only improves the practical applications of these techniques, but also contributes to the broader field of digital fabrication, paving the way for innovative solutions in a variety of industries.

5. ACKNOWLEDGMENTS

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