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DESIGN AND FABRICATION OF CURVED SHAPED LITHOPHANE WITH THE HELP OF FDM 3D PRINTER

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ABSTRACT

Lithophanes are intricate three-dimensional reliefs that transform grayscale images into luminous artworks when backlit, relying on variations in material thickness to modulate light transmission. While regularly it is produced on flat surfaces, curved lithophanes offer enhanced visual depth, structural integrity, and application versatility. This research presents a comprehensive methodology for fabricating curved lithophanes using additive manufacturing techniques. We develop a mathematical model that maps 2D grayscale images onto cylindrical geometries by transforming pixel intensities into variable thickness profiles. The process incorporates image preprocessing, geometric mapping, mesh generation, and fabrication via fused deposition modeling (FDM) using translucent thermoplastics. A detailed case study involving a 55 mm tall lithophane with a thickness range of 1 mm to 3 mm and 180° curvature demonstrates the practical implementation of this technique. Experimental evaluation confirms that curvature improves light dispersion and contrast perception, making curved lithophanes ideal for personalized lighting, medical visualization, and artistic design. This study establishes a reproducible framework for the design and 3D printing of curved lithophanes, paving the way for future innovations in functional and aesthetic fabrication.

Keyword: - Lithophane, Fused deposition modelling and Image processing.

1. INTRODUCTION

Lithophanes are an elegant blend of art and engineering, historically crafted from thin porcelain sheets whose varying thicknesses revealed intricate grayscale images when backlit. Originating in 19th-century Europe, these translucent reliefs relied on meticulous manual carving and kiln-firing techniques, requiring significant artisanal expertise and offering limited reproducibility. The core principle remains consistent across generations: image luminance is encoded through differential material thickness, with darker image regions corresponding to thicker, less translucent zones, and lighter areas rendered as thinner, light-permissive segments [1,2,3,4,5].

The advent of digital manufacturing, particularly additive techniques such as fused deposition modeling (FDM), has transformed lithophane production. With computational tools and desktop 3D printers, lithophanes can now be generated automatically from digital images, allowing rapid prototyping and customization. FDM-based lithophanes are fabricated layer-by-layer using translucent thermoplastic filaments, such as PLA, which exhibit favorable optical properties under transmitted light [6]. This approach democratizes lithophane creation, enabling high-resolution output with minimal manual intervention. While the majority of 3D-printed lithophanes are planar, recent advancements have extended these methods to non-planar, curvilinear geometries. Curved lithophanes such as cylindrical and spherical forms introduce significant functional and aesthetic advantages, including improved light distribution, enhanced structural integrity, and increased surface immersion. However, these benefits come with added complexity in geometric transformation, surface mapping, and toolpath optimization. Accurate image projection onto curved surfaces necessitates robust mathematical modeling and careful calibration of image-to-thickness mapping across non-Euclidean domains [16,17].

This study explores the modern techniques underlying lithophane fabrication, with a particular emphasis on curved forms produced via fused deposition manufacturing (FDM). We introduce an algorithmic workflow that bridges digital image processing with 3D geometric modeling and fabrication. By integrating traditional artistic principles with cutting-edge manufacturing capabilities, curved lithophanes exemplify the convergence of heritage and innovation in contemporary design.

3D printing offers a more efficient and accessible approach, allowing artists and designers to produce intricate and personalized lithophanes with ease. The choice of 3D printing material, image processing algorithm, and printing technique can all impact the quality and appearance of the final lithophane product. Materials such as PLA, PETG and nylon have been shown to produce high-quality lithophanes, while image processing algorithms such as the grayscale algorithm and depth map algorithm can be used to create lithophanes with varying levels of detail.

2. METHODOLOGY

The method used in lithophane production involves a combination of image processing, 3D modeling and 3D printing technique [11,12,21]. The success of the lithophane production process depends on careful selection of images, proper image processing and appropriate choice of printing parameters.

2.1 Steps involved in the process

1) Image Selection: The first step is to select an appropriate image for the lithophane. Typically, images with high contrast and varying shades of gray are preferred.
2) Image Processing: The selected image is processed using specialized software to convert it into a grayscale image and to enhance the contrast between different parts of the image.
3) Lithophane Generator: A lithophane generator is used to convert the processed image into a 3D model. The generator creates a 3D model with varying thickness, where the thinnest parts of the model correspond to the brightest parts of the original image, and the thickest parts correspond to the darkest parts of the image.
4) 3D Printing: The 3D model is then 3D printed using a Fused Deposition Modeling (FDM). The choice printing parameters can have a significant impact on the quality and visual appearance of the lithophane.
5) Post-Processing: Once the lithophane is printed, it may require some post-processing steps to improve its visual quality. This can include sanding, polishing, or painting the surface of the lithophane.

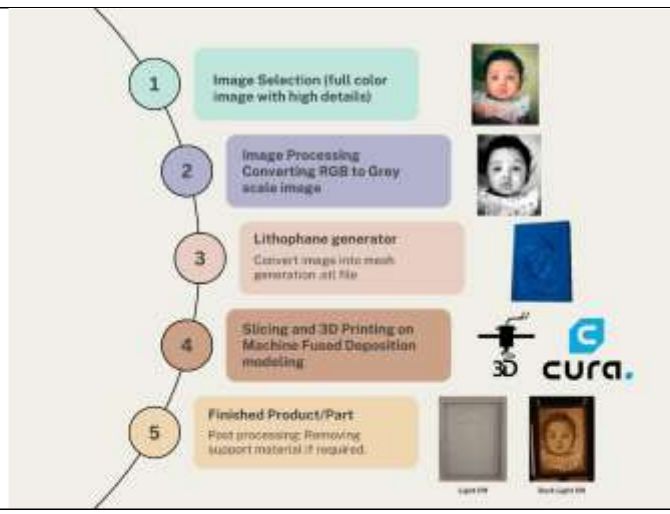

Figure 1: Flow chart of lithophane making process.

Lithophanes can be created in a variety of software tools like 3DPRocks, Lithophane maker, its litho, Luban 3D etc. we are using 3dp.rocks/Lithophane website is preferred because It is simple to use and has 8 different layouts for model design. It makes easy to upload a photo and download a model for 3D printing but for best results, the photo should be edited. Conversion of RGB full color image into Grey scale image we have to change brightness and contrast in image [13,14,15].

- Brightness: Brightness typically refers to the overall intensity of light in the image. It determines how much light is allowed to pass through different parts of the lithophane, affecting the level of illumination for various areas. Adjusting the brightness can influence the contrast and visibility of details in the final lithophane.

- Contrast: Contrast is the difference in luminance or color between different parts of the image. In lithophane creation, adjusting contrast can enhance the distinction between light and dark areas. Higher contrast can result in a more visually striking and detailed lithophane, while lower contrast may lead to a softer, more subtle effect. By keeping proper balance of both brightness and contrast best lithophane quality can be achieved.

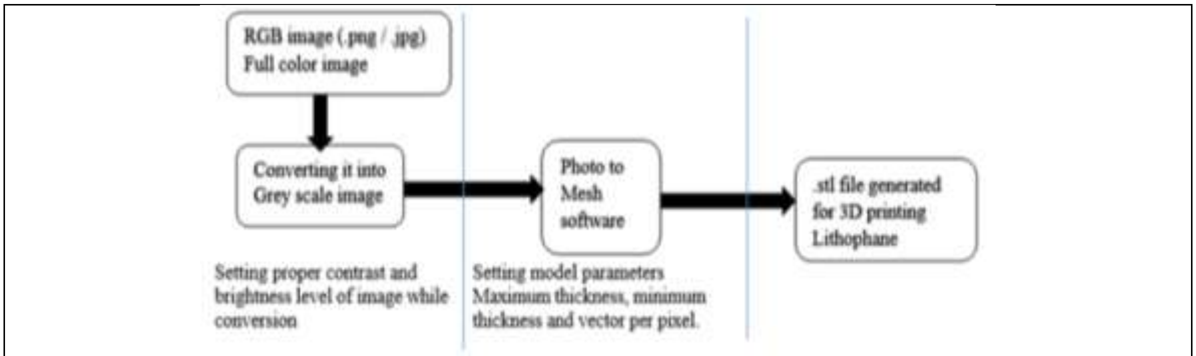

Figure 2: Flow chart for conversion of RGB image to .stl file [21,22].

2.2 Mathematical Model

Creating a lithophane with a curved shape involves translating a grayscale image into a 3D representation where the thickness of the material varies according to the pixel intensity. The mathematical foundation for a curved lithophane can be described as follows:

1. **Input Image Representation**
   Let I(x,y) represent the grayscale intensity of the image at position (x,y),
   Whereas, I(x,y) ranges from 0 (black) to 1 (white).

2. **Mapping Thickness to Intensity**
   Define the material thickness T(x,y) as: $T(x,y)= T_{min}+(T_{max}-T_{min})\cdot I(x,y)$

   Whereas, Tmin: Minimum thickness (for black regions).
   Tmax: Maximum thickness (for white regions).

3. **Curved Surface Mapping**
   to create a curved lithophane (e.g., cylindrical or spherical), map the thickness to a curved coordinate system. For a cylindrical lithophane:

   $X= R \cos\left(\frac{x}{w}\ \theta_{max}\right)$ ---1 $\quad$ $Y= R \sin\left(\frac{x}{w}\ \theta_{max}\right)$ ---2 $\quad$ Z= (y S) + T(x,y) --- 3

   Whereas,
   R: Radius of the cylinder, W: Width of the image, θmax: Maximum angular range of the lithophane, S: Scaling factor for vertical mapping, T(x,y): thickness based on grayscale intensity.

Let's work through an example step by step, considering desired parameters to make a curved lithophane:

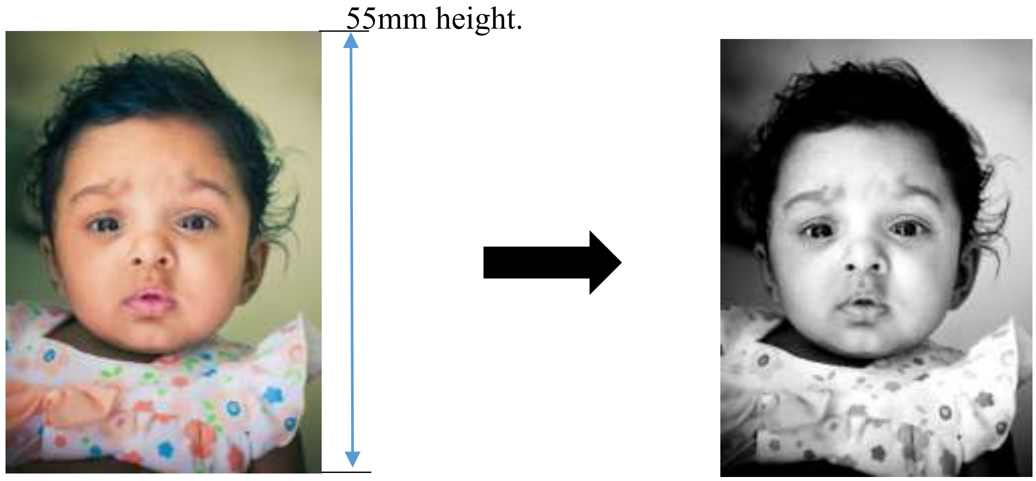

Figure 3: RGB to gray scale conversion, adjusting brightness and contrast [20].

If input image height is fixed to 55 mm then as per the proportionate the image width will be 39.216mm

Now we will calculate the Radius (R) required

For a cylindrical lithophane, the width of the image determines the required radius R. The image wraps around the cylinder, meaning its width corresponds to the arc length of the cylinder:

W (arc length) = R θ_{max}

If we assume a semi-cylindrical lithophane (half-wrap), we use:

θ_{max} = π (180 degrees or half-circle)

Hence $R = \frac{W}{\pi}$

$R = \frac{39.216}{3.1416} \approx 12.48\text{mm}$

3. PROCESS OF MAKING LITHOPHANE

Curved lithophanes represent a unique convergence of artistic expression and computational design, allowing grayscale images to be embedded into 3D surfaces that reveal their full form when illuminated. Unlike flat lithophanes, curved versions require additional mathematical transformations and careful parameterization to maintain image fidelity across non-planar surfaces. In this part will provide a comprehensive, step-by-step guide to designing and fabricating a curved lithophane.

Step 1: First take full color RGB image which is to be converted into lithophane.
Step 2: Convert RGB image into Grey scale image by adjusting brightness and contrast.
Step 3: Open 3dprocks webiste to convert image into .stl file, website created by Nested Cube [13].
web link: https://3dp.rocks/lithophane/

Step 4: Choose outer curve shape and import grey scale image, preview of lithophane will be displayed into workspace.
Step 5: Select setting tab→ Model Setting →Change parameters like size, Thickness, border, vector per pixels etc. →click on the model tab and click on Refresh (This would ensure that the print comes out to your preferred dimensions)
Step 6: Select setting tab→ Image Setting →Change negative image to positive image→ click on the model tab and click on Refresh.
Step 7: Export file in .stl
Step 8: Open cura slicing software and import .stl file.
Step 9: 3D model of lithohane will be appear on platform, orientation of the model should be vertical and platform adhesion should be brim. (other settings of cura software are given in below images)
Step 10: save .gcode file and send it to 3D Printer.

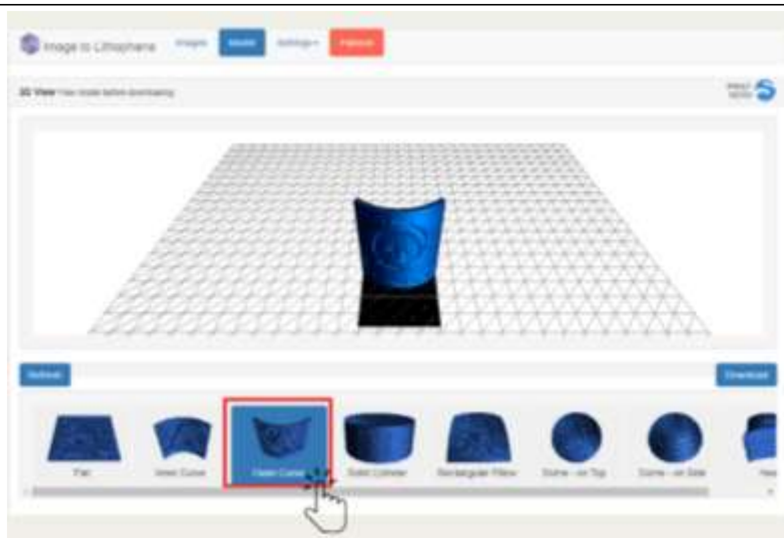

Figure 4: 3DP rocks website, showing preview of curved lithophane generation [13].

Model settings to be followed: maximum size 55mm (image height), thickness 3mm, thinnest layer 1.4mm, border 3mm and vector per pixel 5

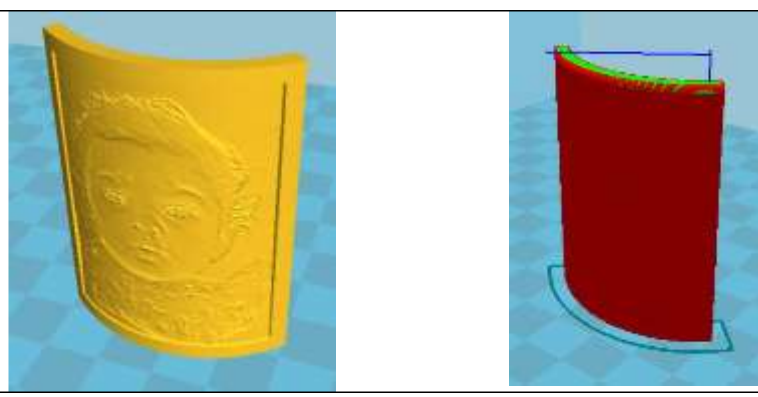

Figure 5: import .stl file in cura slicing software, check toolpath and save .gcode .

White translucent PLA filament is used above 3D printing process, Cura Slicing Software settings as follows: layer height 0.18mm, Shell thickness 2mm, bottom top thickness 0.6mm, infill density 100%, print speed 50mm/s, print temperature 210°c, bed temperature 50°c, platform adhesion skirt, support none, filament diameter 1.75mm, flow 100% and nozzle size 0.4mm.

Figure 6: Machine name Creality Ender 3 (Bed size 220x220x250mm)

4. 3D PRINT RESULT AND ITS DISCUSSION

Curvature significantly influences light transmission in lithophanes by altering how light interacts with the surface and internal geometry.

Light dispersion and distribution, curved lithophanes disperse incoming light over a wider range of angles compared to flat ones. This leads to more even illumination, reducing harsh hotspots and shadows. The curvature acts like a light-diffusing lens, enhancing image smoothness and depth perception. Angle of incidence and refraction, in curved surfaces, light rays strike the surface at varying angles, unlike the mostly perpendicular interaction in flat lithophanes. This variation causes light to bend and scatter differently, often leading to softer contrast and smoother grayscale transitions. It can also reduce direct light loss at sharp angles, improving visibility from multiple viewing positions.

Perceived depth and visual enhancement, the natural curvature creates a 3D illusion, improving visual realism. Shadows and highlights shift as the viewer changes position, adding dynamic visual feedback. The curvature emphasizes spatial contrast, especially in high-relief areas of the lithophane.

Structural thickness and translucency gradient, curved lithophanes may have a more uniform thickness gradient across the surface. This enhances translucency control, giving designers more predictability in how light is transmitted and diffused. However, extreme curvatures might compress or stretch image regions if not properly modeled, affecting light modulation accuracy.

Application specific impacts, cylindrical or spherical lithophanes used in lampshades or light tunnels distribute light more effectively around the viewer. In architectural lighting, curvature enables 360° or panoramic display, making images visible from all directions with consistent brightness.

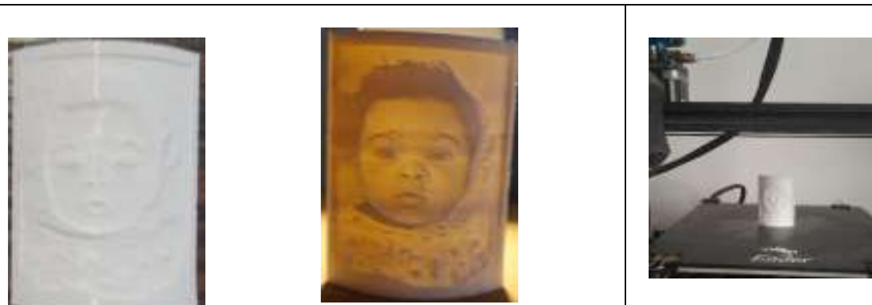

Figure 7: Back light off and back light on results of 3D Print. Left side image showing job orientation on 3D printer machine.

5. CONCLUSION

This study presents a comprehensive mathematical and computational framework for the design and fabrication of curved lithophanes using Fused Deposition Modeling (FDM). By mapping grayscale image intensity to variable thickness and applying non-Euclidean geometric transformations, we demonstrated how planar image data can be accurately projected onto curved surfaces cylindrical and spherical alike without compromising photometric fidelity. The integration of image preprocessing, 3D mesh generation, and structural analysis within a unified computational pipeline enables the precise control of both visual and mechanical performance. Experimental validation confirmed that curvature significantly enhances light diffusion, image clarity, and structural stability.

Moreover, the methodology is accessible, reproducible and compatible with widely available 3D printing technologies and materials. Curved lithophanes offer new frontiers in personalized manufacturing, medical visualization, and architectural design. By leveraging the optical and mechanical advantages of curvature, this approach not only revives a historical medium with modern precision but also introduces innovative pathways for functional and aesthetic applications.

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