Relief stylization from 3D models using featured lines

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Abstract

Digital reliefs mimic the style of their real life counterparts, and hence offer an elegant depiction of a 3D shape. Despite an increasing amount of research on digital relief generation in computer graphics, little has been reported on the generation of abstract sculpture forms using pure engraved lines. In this paper, we present a method to create a relief-like sculpture using lines extracted from 3D Objects. Our relief generation process is different from other previous works: our method uses lines to present the geometric shape while others rely on the smooth surface to convey the shape information. Such a relief-like art piece can be easily machined since only the lines need to be carved.

CR Categories: I.3[COMPUTER GRAPHICS]: I.3.8 Applications

Keywords: sunken relief, line drawings, surface abstraction, computer art

1 Introduction

Lines play an important role in conveying shapes in human perception. Traditional art works have used different sorts of lines to present features and shapes. For example, sunken-relief, also known as intaglio or hollow-relief, is a special type of sculpture artwork which refers to carving the model into a plane [Rogers, 1974] (as shown in Figure 1), where it is noticed that the lines of contours are vivid elements of great importance in presenting the special stylization. Other lines such as interior ones are included to reflect the small features such as the wrinkles of clothes. Traditional reliefs rely on smooth curvy surfaces whose depth varies within a limited range. These surfaces together with their shadowing lead to a faked depth perception when viewed from a particular angle. Even nowadays it is expensive to precisely carve a surface as a relief because it requires special techniques and specially designed tools.

Existing research mainly focuses on the generation of relief-like sculptures by developing complex algorithms to produce the curvy surfaces which convey the impression of depth. Little attention has been paid to the importance of lines in the stylization of sculptures. We notice that the lines can co-exist with a created relief-like sculpture to either enhance or alter the effects. A simplified type of art piece can be easily machined if the lines are only to be carved into a flat the plane. The manufacturing cost is a small fraction compared to making a real relief with complex shapes.

Figure 1: Sunken relief example

Lines can convey shapes to an effective extent, the 3D depth information being encoded through the layout of line combinations. This concept has been demonstrated with line drawings art pieces. In our practice, this type of art piece with simple lines provides a unique stylization which resembles a relief.

Our work takes advantage of the parallel development in the generation of 2D line drawings from 3D objects. Further processing of the lines is necessary before they can be used as inputs to generate a sculpture: a smoothing operation can be applied to the original 3D geometry to prevent too many details which may make the final sculpture look messy; and image-based processing is applied which operates directly on the extracted lines to improve their quality and accuracy.

The methods we utilise have been used in different graphical applications. However, it is inventive to combine them together to create a unique style of sculptures with featured lines. This particular type of relief-like art piece has advantages in manufacturing due to its simplicity and low production costs. The generated

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art pieces can be recognized as stand alone artworks or used as decorations to adorn furnitures, walls, buildings, and jewellery.

2 Related Work

Relief generation with the assistance of computers has been researched for many years. Direct image processing can produce a relief style image via direct operations on pixels [Wang et al., 2010a, Wang et al., 2010b]. However, the results are often pseudo-three-dimensional which do not actually convey real height data and have little use in practical manufacturing.

3D modeling software, such as 3D MAX, Maya, Zbrush, etc. can be used to design digital 3D reliefs (high-relief, bas-relief and sunken-relief) by manually modelling the geometry. The design process mainly relies on human interaction which is tedious and time-consuming, requiring special skills and expertise [Wang, 2010b].

Recent research has developed many algorithms about relief production by converting 3D models into reliefs . The very first two works appeared in 1997 [Cignoni et al. 1997] and 1999 [Belhumeur et al. 1999] respectively. Cignoni et al. [1997] proposed a relief generating system for generating 3D bas- and high- relief from 3D surface models. Belhumeur et al. [1999] tackled the problem by investigating the ambiguity of bas-relief generation with respect to surface reconstruction. The methods of relief generation based on geometric processing were developed recently in [Kerber et al. 2007a; Kerber et al. 2007b; Weyrich et al. 2007; Kerber et al. 2009], where the ideas and concepts from the high dynamic range imaging were specially adopted for this purpose. In order to flatten a 3D scene into a relief with limited depth, a high compression ratio is required. After compression, the quality of the shape should not be degenerated, that is, the relief should not blur and distort the visual features of the input when viewed from a given angle. Weyrich et al. [2007] applied a silhouette preserving diffusion filter to achieve this goal. Kerber et al. [2009] recommended use of the bilateral filter and Sun et al. [2009] promoted the use of the adaptive histogram equalization respectively. Later work of Kerber et al. [2010] boosted the efficiency of relief generation by expanding their previous development.

Shape from shading [Rados and Faugeras, 2005], methods have shown that it is possible to construct a 3D shape given a single image. But they have their own particular limitation, as they may not work well without the user's close intervention. Recently, Alexa and Matusik [2010] proposed a method for the automatic generation of relief surfaces that could produce the bas relief-like effects under directional illumination. Their method uses image as input. An optimization process is adopted to create the smooth height information for relief pieces.

All the prementioned works exemplify the generation of smooth curvy surfaces in reliefs which convey the depth and shape information. Few people pay attention to the importance of lines in the sculpture art pieces. A unique stylization of relief-like sculpture can be created with the proposed method, that only involves abstract lines and does not need to derive surface shapes. Our work, to some extent, has underlying links to the previous works in relief generation as they share the same objective- to flatten a 3D object into a plane or a shallow space with limited depth range.

3 Implementation

In our method, we first extract the line drawings from a given 3D object, and then put into effect with techniques developed by Rusinkiewicz [2008]. A pre-processing process is then applied to the line drawings images to clear the unwanted noise for the relief generation. Alternatively, for models with fine local details, a Laplacian smoothing step can be applied to the geometric model to remove some unwanted details before the line drawings extraction. The prepared line drawings then can be used to create our relief-like art pieces.

3.1 Line drawings

In the example of a sunken relief (see Figure 1), the principal lines are almost invariably the external contours which are determined by the shape of the object itself and by the viewer's perspective. In addition, several other linear features may be present in a relief with secondary lines. From the perspective of a human, those lines have an important relation to the conveying of the 3D geometric information. As an example, line drawings can encode rich information, of features, geometry and textures. This leads us to the hypothesis that a sculpture using only carved lines is capable of conveying complex geometry and exhibits a special stylization of relief-like art pieces. Using lines only saves the effort involved in identifying surfaces with varying depth in traditional relief modeling.

3D line drawings has been well studied in the computer graphics community. This refers to extracting lines from 3D models to present the most salient features of the model. Lines not only include contours but other types of details, like suggestive contours, creases etc [Koenderink, 1984; Raskar, 2001] which can be used as a stencil for initial guidance in our sculpture generation.

There are two major classes of algorithms for extracting most kinds of lines from 3D meshes: image-space approaches and object-space methods. Image-space algorithms [DeCarlo et al. 2003, Ashikhmin, 2004] render a depth map or cosine-shaded model, and then extract lines by doing image processing on the framebuffer. The advantage of this type of algorithm is that it is fast, easy to implement, and provides some notion of view-dependent level of detail. A major disadvantage is that it is difficult to control the appearance and stylization of the resulting lines.

Object-space [DeCarlo et al. 2003] algorithms extract lines directly from the surface using curvature information. These algorithms tend to be more complex than their image-space counterparts, and it is technically challenging to adapt them in a way that they can take advantage of application to graphics hardware. On the other hand, they provide good control over stylization.

Extracting lines from 3D models requires an understanding of the basics of differential geometry [Do Carmo, 1976]. Occluding contours and silhouettes are the most ubiquitous example of first-order, view-dependent lines. In a very similar way, different kinds of lines, like suggestive contours, will have definitions that depend on higher-order derivatives. Finally, ridges and valleys involve local extrema of curvature; hence they are third-order.

Our development is mainly based on the existing work by [Rusinkiewicz, 2008] to obtain lines drawings from 3D models. It is noticed that directly applying the output is not suitable for generating relief-like sculptures, since there are some unexpected breaks in the contours and dots by noise (as shown in Figure 2(b)) or too many line details (as shown in Figure 4(a)). Additional pre-processing is intoduced to tidy up the image.

Normally, there are two alternative ways to achieve pre-processing; these depend upon the type of model. For models with smooth surface like the horse in Figure 2, digital image processing is highly efficient, easy to implement and can produce good results. For models with many local variations, mesh operations like smoothing can be applied.

3.2 Pre-processing: Image processing

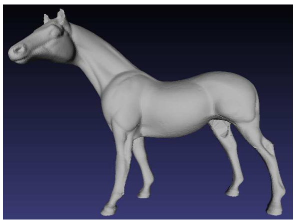
Image processing can be applied to the extracted line drawings to enhance their quality for further processing. The advantage of applying digital image processing is that it is fast and easy to implement. Figure 2(a) shows the input horse model.

In Figure 2(b) one can see that there are some breaks and noises which are not appropriate for relief-like sculpture generation. Smooth, concise and successive boundary lines are expected.

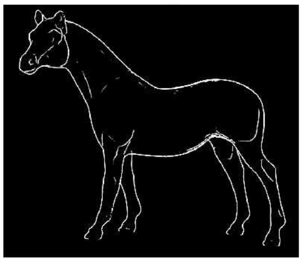
In order to emphasise lines in our sculpture, we firstly remove the minor noise. Let I_i denote the extracted 3D line drawings image, with binary pixel values at a given position (x, y) in the image space.

$$I_i = I(x, y) \tag{1}$$

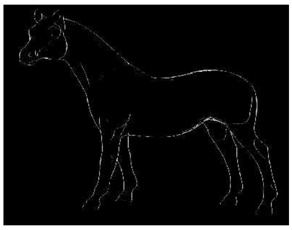
An effective and simple way to achieve the desired goal is to apply erosion.



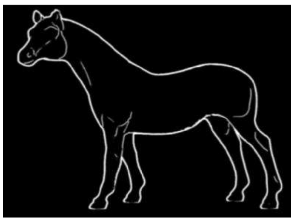
(a) *Input horse model*



(b) *Converted image of line drawings*



(c) *Lines after erosion*



(d) *Lines after dilation*

Figure 2: Image processing example of the generated lines of the horse model

To perform the erosion operation, a structure template T is defined as a stencil. Erosion is a process of thinning the lines. Translating the template a certain distance (x, y)

in the image space leads to $T_{x,y}$ .If $T_{x,y}$ is part of the initial input binary image, $T_{x,y} \subseteq I_i$, the pixel value at position (x, y) remains unchanged, otherwise it is set to zero. Equation (2) describes the erosion operation:

$$I_i - T = \{(x,y) | T_{x,y} \subseteq I_i\} \quad (2)$$

The next step is to recover the image by dilating the image to fix the holes and breaks and achieve the final image as shown in Figure 4(d). Dilation is the inverse operation of erosion. Given a template T, for instance, the dilation can be described as:

$$I_i + T = \{(x,y) | T_{x,y} \cap I_i \neq \phi\} \quad (3)$$

Both erosion and dilation can be repeated several times until satisfactory results are achieved.

3.3 Pre-processing: mesh smoothing

For some models like the bunny, there are too many small local variations, (as shown in Figure 3). Therefore, it is necessary to pre-process the mesh and extract the lines afterwards. This is to control the density of the lines and thus to influence their presence in the final sculpture. We opted to smooth the mesh to get rid of unwanted details and to make the final relief-like sculpture as clear as possible. Taking the bunny model as input as shown in Figure 3. Figure 4(a) shows the extracted lines of the initial model; it is noticeable that there are so many details that require much effort during the final sculpture generation. The following Figures 4(b, c, d) show the results after 3 different levels of smoothing. Standard Laplacian smoothing was used which changes the position of nodes without modifying the topology of the mesh (Vollmer et al. 1999). For each vertex in a mesh a new position is chosen, based on local neighbours, and the vertex is moved to an average position. The smoothing operation can be described as:

$$\mathbf{v}_i = \frac{1}{N} \sum \mathbf{v}_j \quad (4)$$

where N is the number of adjacent vertices to the vertex in operation, $\mathbf{v}_i$ is the vertex in operation and $\mathbf{v}_j$ are its neighbours.

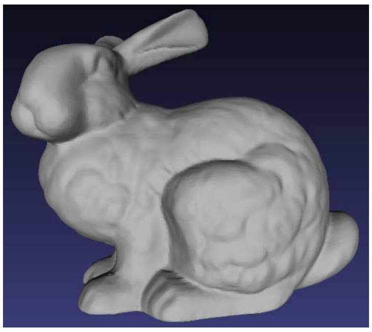


Figure 3: *Bunny model*

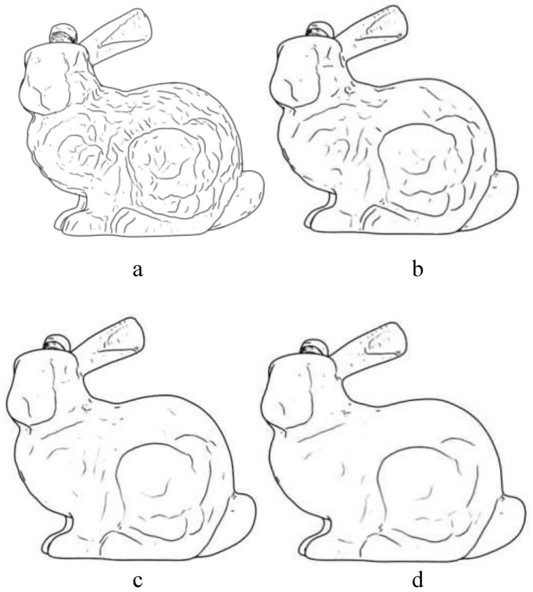


Figure 4: *Line drawings of the bunny model with different levels of smoothing*

3.4 Sculpture generation

(a) *Result without smoothing.*

(b) *Result with smoothing*

Figure 5: *Comparison of reliefs with different line density*

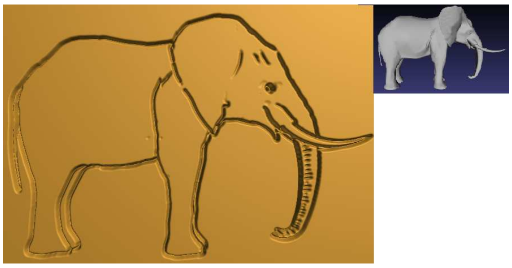
After obtaining the required line information, the mesh of a 3D relief-like sculpture can be generated with the shape of the generated sculpture represented by a triangular mesh. The x and y components of each vertex position correspond to the location of their counterpart in the line image I. The z components are derived from the entries; this operation is explained as follows:

$$z = sf \cdot I(x,y) - os \tag{5}$$

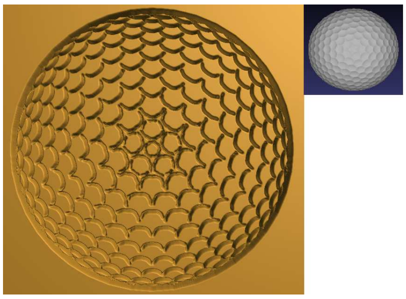
where $I(x, y)$ is the image pixel value after the aforementioned pre-processing, which corresponds to depth z, os is the offset value and sf is the scaling factor. This leads to a sculpture in which the background is mapped to a zero-level and each line is carved deeper into the material, controlled by the scaling factor.

Pre-processing can be regarded as a specially designed filter which controls the quality and stylization of the final sculpture effects. To give an example, Figure 5 (a) and 5(b) are created with images of Figure 4(a) (without smoothing) and 4(d) (with smoothing) respectively: although the same initial 3D geometry of the bunny is used, both sculptures exhibit different stylization with varying line densities. We recognize Figure 5(b) bearing the main shape features with sufficient details not to distract the viewer with too many small strokes.

(a) *Horse model*



(b) *Elephant model*



(c) *Golf model*

Figure 6: *Reliefs generated with our method*

Figure 6 demonstrates the capabilities of our technique for the complex objects. For example, using the golf ball model, one can see that the variation of lines can convey a convincing 3D geometric variation of depth even though they are engraved into a flat plane.

4 Conclusions

In this paper, we have proposed a method for generating relief-like sculptures of a given 3D geometry. After obtaining the line information from a 3D object using the line drawings extraction technique, we pre-process the line drawings images to enhance the input. Two strategies exist depending on the types of the 3D models. For models with smooth surfaces, digital image processing usually achieves the desired results; for those with many local variations, mesh smoothing is preferred. Having obtained the necessary line information, we then triangulate it into a 3D mesh representation of the relief. The advantage of our algorithm is that it is fast, easy to implement, and can benefit the subsequent process of manufacturing. No complex curvy surfaces are involved in our stylization and only the engraved lines adopted to represent the shape features.

Currently, our work is limited to creating relief-like effects with feature lines available. In our future work, we will develop complex reliefs that combine both feature lines and curvy surfaces organically in order to convey the depth variation and highlight the more distinctive shape features.

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