Converting Image into Bas Reliefs Using Image Processing Techniques

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Abstract. In this study, we develop an application to convert an image into bas reliefs, a kind of 3D sculpture on a flat surface, by using image processing techniques. First, the color image is converted into gray image, and then is used as a base surface in xy-coordinate. Two different methods for determining height in z-coordinate provides two different carving styles. In the first method, the height is specified by using gray value of the blurred image, while the second specifies the height by using gray value of the dilation of the edge image. Frame effect is then created by adding a flat plane around the carving. The experiment shows that the application can transfer visual contents of the image into the bas reliefs and also can generate artistic reliefs model easily.

1. Introduction

As a branch of visual arts, reliefs are a type of 3D sculpture whose sculpture elements are attached to the surface as a base. As a historical heritage, examples of reliefs can be found on the walls of temples, monuments, museum fences, or others. On these historical objects, the reliefs are mostly created to capture the important events or figures in the past. Today, aside from being a decoration on the walls of a building, reliefs are also applied to medals, product packaging, coins, souvenirs, and many other objects. Based on the height and projection degree of sculpture against the base surface, there are two types of reliefs, namely high and bas reliefs. In the high reliefs, the height difference between the sculpture and the base surface is greater than in the bas-reliefs. In addition, the sculpture in the high reliefs also has a projection degree that is greater than in the bas reliefs. Details of the sculpture on the high reliefs can be seen clearly from the front and side. While the sculpture details on the bas relief are only clearly visible from the front. Figure 1 and 2 show examples of the high and bas reliefs, respectively.

Creating reliefs manually requires high sculpting skills that not everyone has. Some methods have been developed to ease the creation of 3D models, such as sketch-based model deformation [1-3] and multi-resolution surface framework [4]. In addition to those studies, it will be helpful if there is a study for providing a specific software tool that can assist people to create reliefs even though he has no sculpting skills. The assisting software can be used to produce 3D reliefs models which further can be printed into a real reliefs object using 3D printer. Previously, there have been some efforts to develop algorithms for creating 3D relief’s models automatically. Some of those algorithms convert input data in the form of 3D models which represent objects in the real world into 3D reliefs models [5-6]. While...
some other algorithms do the conversion using input data in the form of 2D images [7-10]. The input data in the form of 2D image which is usually collected using a camera is easier and cheaper to be prepared than the input data in the form of 3D model which is collected using a 3D scanner.

There are several studies in converting 2D image into 3D bas reliefs reported in literatures. Alexa et al. [7] use a discrete surface model, which is developed at a specified illumination condition. Each pixel in image is connected to some elements of the model, which is further used to generate the reliefs. This approach can produce a relief with sufficient degrees of freedom, but it is sensitive to the illumination changes. Wang et al. [8] use an approach based on gradient operations to generate the bas-reliefs. First, the approach modifies gradient fields of the image using a sequence of processes, i.e. calculating image gradients, smoothing the gradients, and enhancing fine features in image. Furthermore, the image height which is determined by the modified gradients, is used to represent triangle mesh of the 3D bas reliefs by placing a vertex at each pixel in the image. Wu et al. [9] generates a 3D bas relief by firstly determines layers based on relative depth ordering of objects in the image, and then reconstructs surface using intensity and gradient information. Suciati et al. [10] generate sequence of curves on 3D flat model by finding list of control point’s curves based on gradient information on image, and then drawing cubic B-spline curve on a flat canvas.

This study aims to develop an application to convert a 2D image into 3D bas reliefs using image processing techniques. Those techniques include converting color space of image, detecting edge in image, and thickening the edge, which are used to generate bas reliefs with several different styles. The application is expected to help a user without sculpting skills to create bas relief cheap and easily.

2. The proposed algorithm

The algorithm to convert 2D image into 3D bas reliefs is shown in Figure 3. There are two input data given to the algorithm. Those are a color image and a reliefs style. Firstly, the color image which is in the Red Green Blue color space, is converted into the gray color space. Then, the image in the gray color space is used as a base surface in xy-coordinate. All pixel in the gray image become a vertex of the base surface. Height of each vertex is modified according to the gray value of the associated pixel. The algorithm can create two style of bas reliefs. In the first style, the gray image is blurred using average filter with kernel size 9 x 9. In the second style, edge of the gray image is detected using Canny method, and then the edge is thickened using morphological dilation with disk structuring element. The gray values of the resulting image are multiplied by 0.02 for high carving or by -0.02 for low carving, and then are used to specify height of each vertex of the base surface in z-coordinate. In order to give thickness effect to the 3D reliefs model, the height of all vertex on z-coordinate is added by 1. Frame effect is then added to the 3D model by augmenting flat plane on each sides of the base surface. Finally, all vertex position is stored into 3D model representation using ‘obj’ file structure. Each process is explained in more detail in the following sub-sections.

2.1. Converting color image into gray image

The input is a color image represented in the RGB color space, which is based on human perception of colors. In this space, various colors are produced by adding red, green and blue lights. The RGB color image is converted into gray image using formula \( \text{gray} = 0.299*R + 0.587*G + 0.114*B \). Example of a gray image is shown in Figure 4.
2.2. **Blurring image using average filter**

Blur images are images that resulted from camera that is out of focus. Pixels that should be seen as sharp points get smeared out, usually into a disc shape. In image processing terms, each pixel in the source image gets spread over and mixed into its neighbor pixels. In other words, each pixel in the destination image is made up out of a mixture of neighboring pixels from the source image.

In order to perform image blurring task, a convolution operation is needed [11]. A convolution is performed by sliding a rectangular array of numbers over the source image. The rectangular array is called the convolution kernel. The new pixel in the destination image is computed by adding the multiplication of a pixel in the source image and a corresponding number from the kernel over the pixel.

In this research, the blur image is resulted from an average filter, that is, a 3x3 kernel composed of 1/9 values. The filter values are all add up to 1, hence, the resulting image will be as bright as the original one. Example of the blurred image is shown in Figure 5.

2.3. **Edge Detection by using Canny method**

Edge is a curve which is often associated with an object's boundary. Edge detection is a process to find the edges of the objects in an image. Many edge detection operators have been proposed for edge detection methods such as Canny, Sobel, Prewitt, Laplacian of Gaussian, and Differential. They have weakness and strength. However, the Canny operator is different to other operators, in which it uses a threshold to detect strong edges and another threshold to detect weak edges. In the end, the weak edges will be detected as edges only if they connected to the strong edges. Therefore, this operator is less affected by noise and can detect weak edges.

Canny edge detection method was developed by John F. Canny in 1986 by using a computational approach. He followed three criteria to improve the previous edge detection method. First, the proposed method must have the low error rate. It means each edge occurred in an image should not be missed and each non-edge should not be responded. Second, the edge points must be well localized (the distance between the edges pixel detected by Canny and the actual edge must minimum). And the last is the method should have one response only to an edge.

Based on these criteria, the Canny edge detection method has six steps. The first is to filter any noise in the original input image by using the Gaussian filter. The second is finding the strength of the image by computing image gradient. The third is computing the direction of the edge by using the gradient in the x and y-direction. The fourth is relating the edge direction to a direction which can be traced in an image. The fifth is applying a non-maximum suppression to suppress any pixel which is not considered to be an edge. And the last is eliminating streaking. The example of the Canny result is shown in Figure 6.
2.4. Thickening Edge using Dilation
Mathematical morphology gives an approach to a digital image procession which is based on shape. The appropriate used of mathematical morphology serves the essential shape characteristics and omits the irrelevance shape characteristic. Dilation is the morphological transformation which combines two sets element by using vector addition. For example, if we have a set \( A = \{(0,1), (1,1), (2,1), (2,2), (3,0)\} \) and a set \( B = \{(0,0), (0,1)\} \), then the result of \( A \) dilation \( B \) is \( \{(0,1), (1,1), (2,1), (2,2), (2,3), (3,0), (0,2), (1,2), (2,2), (2,3), (3,1)\} \).

In the image processing method, we can refer \( A \) as the binary image, \( B \) as the structuring element, and the element value of each set is the position of the white pixel. There are many shape we can use as the structuring elements, such as diamond, disk, line, octagon, rectangle, square, cube, cuboid, sphere, and arbitrary. The example of the dilation proceeds using disk structuring element with radius 2 is shown in Figure 7.

2.5. Determining height using scaled version of gray values
Gray values of the blurred image and the thickened edge image have range between 0 to 255. To determine vertex height of the base surface proportionally, those values must be scaled down. In this study, height is calculated by multiplying the gray value with 0.02, which produces height range between 0 to 5.1, to create high carving. While a low version of carving is created by multiplying the gray value with -0.02, which produces height range between 0 to -5.1.

2.6. Adding thickness and frame effect
At this stage, we get a very thin 3D reliefs model. In order to thicken the model, \( z \)-coordinate of each vertex in the 3D reliefs model is added by 1 and then, a flat surface is created at \( z=0 \). The frame effect is created by adding flat plane around the 3D reliefs model.

2.7. Creating 3D model representation
We use polygonal-based model to represent the 3D bas reliefs. In this kind of model, the 3D bas reliefs is represented by a set of vertices at the surface surrounding the reliefs. Besides storing the vertex positions, the model also store topology of the vertices. The topology contains connectedness information between vertices, which is used to create a set of faces (polygons).

3. The experiment
The experiment is carried out by converting two images, namely tulips and house, into 3D bas reliefs using the algorithm that has been proposed. The tulips image represents a group of images with low color variations. While the house image represents a group of images with high color variations. In addition to the using of two carving styles, the experiment is also carried out by varying the carving height. As explained in the chapter 2, styles of the bas reliefs are determined in 2 ways. The first uses the gray value of the blurred image, and the second uses the gray value of the thickened edge image. The carving heights are varied by multiplying the gray value by 0.02 to increase the carving, and multiplying it by -0.02 to decrease the carving. The bas reliefs converted from the tulips image are shown in Figures 8 and 9. The Figure 8 shows a style of bas reliefs made using gray values of the blurred image. The Figure 9 shows a bas relief style created using gray values of the thickened edge. In each style, there are two variations of carving height, namely high and low carving. The creation of the bas
reliefs by using the tulips image as input can produce good carving, meaning that the proposed algorithm can successfully transfer the visual information in 2D image with low color variations into 3D carving.

The second experiment is done using the house image as input. Intermediate results consisting of gray, blurred, edge and thickened edge images are shown in Figure 10, 11, 12, and 13, respectively. The bas reliefs converted from the house image are shown in Figures 14 and 15. The figure 15 shows a style of bas reliefs made using gray values of the blurred image and consists of high and low carving. Both bas reliefs contain similar visual information with the house image. The figure 16 shows a bas relief style created using gray values of the thickened edge. If we look at the bas reliefs in the figure 16 carefully, then we can find out immediately the difference of visual content between the bas reliefs and the house image. In the bas relief we cannot find the shape of visual elements, such as house, tree, leaves and paving stone clearly, in which those objects are clearly seen in the image. While handling the input image with high color variations, the proposed algorithm works well in generating a style of bas relief which is created using gray values of the blurred image, but performs rather poorly in producing a style created using gray values of the thickened edge image.

4. Conclusion
In this study we have developed an application to convert an image into a bas relief using image processing techniques. Two styles of the bas reliefs can be created using the application, namely content and edge styles. The content style is created using gray values of the blurred image, and the edge style is created using gray values of the thickened edge image. In each style, there are two different scales used to determine the height carving, which produces low and high carving. The experiment is done using two images. One image represents a group of images with low color variations, while another represents a group of images with high color variations. Generally, the proposed algorithm can transfer visual contents of 2D image into 3D bas reliefs successfully and can produce artistic reliefs’ model easily. However, improvement is required to handle input data in the form of 2D images with high color variations.

**Figure 8.** The bas reliefs created using gray values of the blurred version of the tulips image. The reliefs in the left is created using high carving, while the right is created using low carving.

**Figure 9.** The bas reliefs created using gray values of the thickened edge of the tulips image. The reliefs in the left is created using high carving, while the right is created using low carving.
Figure 10. The gray version of the house image
Figure 11. The blurred house image
Figure 12. The edge of the house image
Figure 13. The thickened edge of the house image

Figure 14. The bas reliefs created using gray values of the blurred version of the house image. The reliefs in the left is created using high carving, while the right is created using low carving.
Figure 15. The bas reliefs created using gray values of the blurred version of the house image. The reliefs in the left is created using high carving, while the right is created using low carving.

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