

BOURNEMOUTH UNIVERSITY

TRANSFER DOCUMENT

**From Brush Painting to
Bas-relief**

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ABSTRACT

Bas-relief is an art form part way between 3D sculpture and 2D painting. We present a new approach for generating a bas-relief from a single Chinese brush painting. We do not aim to recover exact depth of a painting, which is a tricky computer vision problem, requiring assumptions that are rarely satisfied. Instead, our approach exploits the concept of brush strokes, making each brush stroke possible to generate a correspond bas-relief proxies (depth map of brush strokes), and combine the depth map of brush strokes together to construct the bas-relief model. To segment brush strokes in 2D paintings, we reformulate layer decomposition and stroke segmentation by imposing boundary constraints, which can make strokes smooth and complete. The resulting brush strokes are sufficient to evoke the impression of the consistent 3D shapes on bas-relief, so that they may be further edited in 3D space. This fulfills the request of recomposition in bas-relief design. Currently, our research focus on Chinese brush paintings with relatively sparse strokes. We demonstrate our approach on a variety of Chinese brush paintings, and even some other suitable styles include rose maling paintings and certain watercolor paintings, our approach is able to produce convincing bas-reliefs.

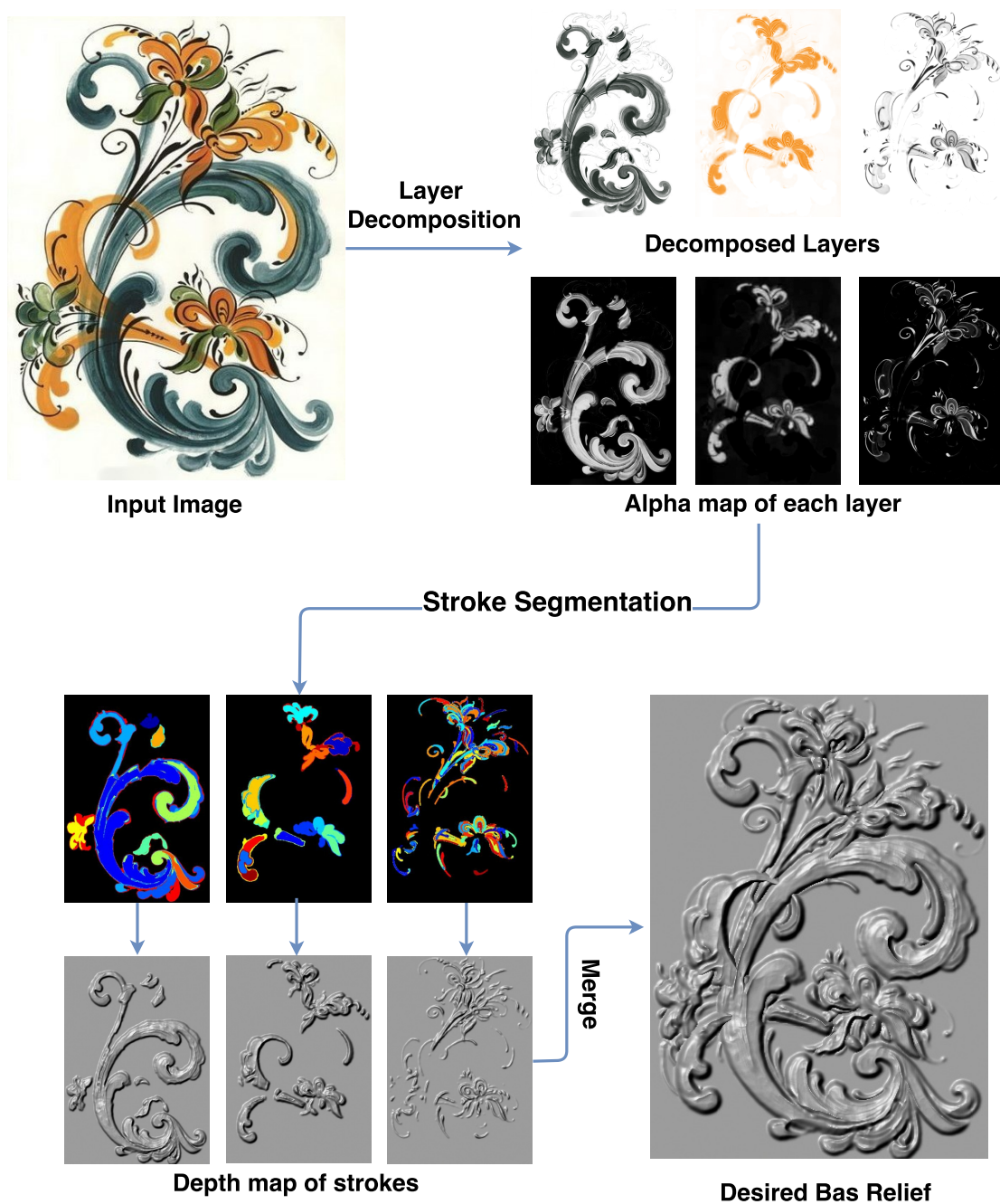


Figure 1: Pipeline Overview

LIST OF BASIC TERMINOLOGY

There are other terms to consider, but many of the important ones are explained in the report where relevant. These are terms not explicitly explained elsewhere.

Height/Depth map: A depth map is an image or image channel that contains information relating to the distance of the surfaces of scene objects from a viewpoint.

Intensity: The measure of brightness of images. In most applications, measured between 0 (dark) and 255 (bright).

Stroke: A mark made by drawing a pen, pencil, or paintbrush across paper or canvas.

Brushstroke: A mark made by paintbrush across paper or canvas.

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Chapter 1

INTRODUCTION

1.1 Background

Relief is a kind of sculpture in which 3D sculpture are carved into a relatively flat surface. In essence, it creates a bridge between a full 3D sculpture and a 2D painting. On this spectrum, high relief is closest to full 3D, whereas flatter artworks are described as bas-relief. Among all the sculpture forms, bas-relief is the closest to 2D paintings [1] [2].

Bas-relief sculpting has been practiced for thousands of years. Since antiquity, artisans from many ancient cultures (including Greek, Persian, Egyptian, Mayan, and Indian art) have created bas-reliefs. Today bas-reliefs are commonly found in a variety of media, commemorative medals, coins, souvenirs, 2.5D animation, and artistic sculptures for blind people. However, crafting bas-reliefs is a laborious, challenging and time consuming process. And with the commonly and cheaply available 3D printing facilities, there is a growing trend in the need of bas-relief art products. There are many ways to reach the same goals more easily with the help of computers. In the past two decades, a sizable amount of research has gone into developing bas-relief generation methods [3].

Bas-relief is regarded as an art form part way between 3D sculpture and 2D painting [3][2][4][1][5]. In general, the existing bas-relief generation methods can also be classified in two different categories with respect to their input [3]:

- 3D model based : using a 3D model (sculpture) as input
- 2D image based : using a 2D image as input

3D model based:

How to generate a bas-relief from a 3D model? The generation of bas-relief from 3D model was first studied in the pioneering work of [6], then various existing 3D model based methods have demonstrate how to compress 3D sculpture(model) into bas-relief [4][1][7][8] . However,this approach requires a 3D model as a starting point.

2D image based:

On the other hand, how to generate a bas-relief from a 2D painting?

There have been some bas-relief generation approaches available based on 2D image in[9][10] and [11]. These approaches almost follow the “bas-relief ambiguity”[12], that is, roughly speaking, from a frontal view the sculpture looks like a full 3D object while a side-view reveals the disproportional depth. A 2D painting can be regarded a image,however, these image based method are focusing on general photograph from real scene,assuming illumination and reflectance are known, and the image is formed from lighting and shading, which obviously unsuited for 2D paintings. Another clear shortcoming is such methods can’t take the Some research focus on bas-relief generation from 2D image of line drawing [13][14][15][16].However,line drawing based methods do not consider how to generate bas-reliefs with surface details: their approaches are limited to using information contained in a line drawing, which are not suited for paintings which contain information such as color,texture and stroke shape,etc.

As mentioned above, bas-relief is a art form part way between 2D painting and a full 3D sculpture[3][4][1][5][9] .And among all the sculpture forms, bas-relief is the closest to 2D paintings,as claimed by [1] [2], while how to generate bas-relief from artistic paintings remains a problem .

The aim of our research is to provide a method to generate a bas-relief from a Chinese painting. We also argue that because most Chinese paintings are produced with individual brush strokes, generating bas-relief surface from each brush stroke would preserve the original features of the painting.

In our bas-relief generation process, although there is no 3D model available from input Chinese painting, preserve the style and features of the painting is crucial in preserving the artistic essence.

Most Chinese paintings are typically sparse with each brush stroke drawn very purposefully[17],and in Chinese painting each stroke exists on its own

as a piece of art[18]. A Chinese painting can be regarded as the union of brush strokes [19]. Differing from the other bas-relief generation methods, our method will honor this very feature by constructing bas-relief surface from the brush strokes individually. This however demands to conquer several challenges.

First, each brush stroke covers a region on the canvas and they may overlap each other, some quite heavily in a painting. To make sure the information is retained, every brush stroke has to be faithfully extracted.

Second,unlike previous 2D image based methods focusing on photograph, a painting does not obey the rules of lighting and shading, which increase the difficulty to mimic the details on bas-relief surface.

Third, the generated bas-relief should be further editable allowing the artist to rearrange, tweaking and reshaping the bas-relief surface correspond to each brush strokes.

1.2 Motivation

The motivation of this research comes from two sides.First,as mentioned above, bas-relief is a art form part way between 2D painting and a full 3D sculpture[3][4][1][5][9]. Research so far has been primarily done on using 3D model,and some other methods based on a single photograph or line drawing as input. However,how to generate bas-relief from artistic paintings remains a problem .

Second, due to the various styles of painting, it is difficult to come up with a general bas-relief generation method suitable for all 2D paintings. Some paintings may be too abstract for bas-relief generation.One the other hand, for traditional Western painting style developed in the Renaissance,which emphasizes realism[20], previous 2D image based methods may easily handle. Most Chinese paintings are typically sparse with each brush stroke drawn very purposefully[17], and such a feature can be found other painting styles,such as rosemailing painting and certain watercolor paintings. Study bas-relief generation from Chinese painting will naturally push forward the research frontier of bas-relief generation from other painting.

Third, Bas-relief generation has wide applications in making objects such as commemorative medals, coins, souvenirs, and artistic sculptures for blind people.With the commonly and cheaply available 3D printing facilities, there is a growing trend in the need of bas-relief art products. On the other hand, the style and philosophies of Chinese paintings have influenced other paint-

ing styles [20], and as input of our bas-relief generation method, the digital image of Chinese paintings are easily accessible on the Internet. Therefore, designing an efficient method for bas-relief generation from Chinese painting is important both theoretically and practically.

1.3 Contribution of Current Work

Our contributions include,

- (1) Extraction of brush strokes. We develop a novel method to extract brush strokes from input paintings with palette analysis and decomposed layers. Comparing with previous method brush stroke extraction method, our method does not
- (2) Bas-relief generation based on brush strokes. We develop a novel method which may entirely generated every stroke to bas-relief based on the opacity of paintings.
- (3) Recomposition in bas-relief design. Artists may redefine the brush strokes' order and shapes by sketches, which enable recomposition in bas-relief design, making it a useful tool for sculpture artists.

Our experiments show that our method can effectively generate digital bas-reliefs for a range of input images, including Chinese paintings and some rosemailing paintings. We also demonstrate the utility of the decomposed brush strokes for image recoloring and image object insertion and animation.

1.4 Overview

As showed in Figure 1, the approach performs in three steps:

First, based on the point cloud of the input image in RGB space (Figure ??), we select the palette colors of the input brush painting, and based on the palette colors we decompose a input image into different layers with transparency.

Second, the original painting is decomposed into element brush strokes by applying modified MSERs segmentation. Based on our observation, alpha map is more suitable for our MSERs segmentation, so the segmentation is based on the transparency. Third, based on the segmented brush strokes, Shape from Shading algorithm has been applied to generate the depth map of each stroke.

Finally, based on those depth maps of strokes, we can edit the generated bas relief. For editing, we have already generated the 3D proxies for each MSER region, namely, the extracted 2D brush region, so, we can change the

depth of specific stroke on bas relief,we can also stitch them on each other based on the user input and change the shape of a certain stroke with given indicated skeleton. By doing so, we fulfill the request of recomposition in bas-relief design.The resulting 3D proxies of brush strokes are sufficient to evoke the impression of the consistent 3D shapes,so that they may be further edited in 3D space.

1.5 Document Structure

Chapter 2

LITERATURE REVIEW

2.1 Bas-relief Generation from 3D model

A significant amount of methods has been considered bas-relief generation from 3D models,[6] firstly proposed a method which creates bas-relief models by linearly compressing (squeezing) the depth map of 3D models. This method can not handle the depth gap between in 3D models and the output bas-reliefs can not successfully preserve the details on 3D models. Some researchers considered bas-relief generation as a geometry counterpart of the high dynamic range (HDR) image compression problem widely studied in computer graphics[7]. This approach calculates the differential coordinates of the input 3D models, then HDR image process method is applied to compress the 3D models. The output bas-relief can preserve salient feature and de-emphasize the others, but sometimes the bas-relief can be distorted and exaggerated. The methods proposed in [1][5] work on the gradient domain of depth map of 3D models, and rely on the combination of a saliency measure and a feature enhancement technique. these methods produce generally satisfactory bas-relief output, and preserve the features of 3D models, although again some areas can be over-emphasized. [8] generate the bas-relief with a optimized contrast-limited adaptive histogram equalization (CLAHE) method, in which the depth map of 3D model is compressed. Local contrast of depth map can be enhanced in this method, however, the detail preservation requires high resolution depth map from 3D model.

These 3D model based methods can often generate bas-relief with acceptable quality, but they all require inputs in the form of 3D models, which are often difficult and time-consuming to prepare, and obviously unsuited for bas-relief generation from 2D paintings.

2.2 Bas-relief Generation from 2D image

Automatic bas-relief generation from 2D image has recently become a significant research topic. Researches have explored recovering depth information from images specifically for the purpose of generating bas-reliefs.

2.2.1 Shape from shading(SFS) based methods

Some work uses Shape from shading for generating bas-relief from 2D images. SFS is a relative classic way for 3D shape recovery; see Zhang's survey [22]. The computation process normally involved with several concepts : depth $Z(x, y)$, surface normal n_x, n_y, n_z , and surface gradient p, q . The depth can either be considered as distance from viewpoint to query surface or the height from surface to default $x - y$ plane. The normal is perpendicular to the surface gradient, namely $(n_x, n_y, n_z) * (p, q, 1)^T = 0$, the surface gradient is the changing rate of depth in x and y direction.

Shape from shading (SFS) is able to recover the shape of an object from a given single image, assuming illumination and reflectance are known (or assuming reflectance is uniform across the entire image). Many methods have been developed, which may be categorized into four PDEs models[23], (1) orthographic SFS with a far light source [24]; (2) perspective SFS with a far light source[25]; (3) perspective SFS with a point light source at the optical center[23]; (4) a generic Hamiltonian. However, SFS is an ill-posed problem. The notable difficulty in SFS is the bas-relief ambiguity[12], that is, the absolute orientation and scaling of a surface are ambiguous given only shading information. To amend it, many SFS algorithms impose priors on shape, depth cues produced by a stereo system, or assume that the light source, the surface reflectance, and the camera are known[22] [26] [27] [2].

Unfortunately, SFS based methods is assuming illumination and reflectance are known, and the image is formed from lighting and shading, which works well for realistic photographs rather than paintings, simply apply SFS method is not enough to generate bas-relief with acceptable quality . see section !!!!!

2.2.2 Line drawing based methods

Line drawing is a drawing made exclusively in solid lines. Rather than generating bas-relief from a photograph from real scene, some researches focus on bas-relief generation methods from 2D image of line drawing. Kolomenkin

et al.[13] aims to reconstruct a model from a complex line drawing that consists of many inter-related lines. At first, they extract the curves from line drawing. Then, junctions between lines are detected and margins are generated. By analyzing the connectivity between boundaries and curves, they reduce the problem to a constrained topological ordering of a graph. From these boundaries and curves with given depth, they use smooth interpolation across regions generate the bas-relief surface. Similarly, line labeling methods has been applied for shape construction from line drawings [14][15][16]. A labeling process would classify segmented lines into different labels, such as concave, convex and occluding, and these labels can give clues for the shape generation of bas-relief. [16] proposed a bas-relief generation method consists of six main steps: segmentation, completion, layering, inflation, stitching, and grafting. This method combines user indications and shape inflation to model smooth bas-relief shapes from line drawings.

However, line drawing based methods do not consider how to generate bas-reliefs with surface details: their approaches are limited to using information contained in a line drawing, which are not suited for brush strokes which contain information such as color, texture and stroke shape.

2.2.3 Gradient and intensity based methods

Wang et al.[28] demonstrate a method by constructing bas-reliefs from 2D images based on gradient operations. In their research image gradients were calculated, then by smoothing gradients to smooth shape changes. Finally, they boost fine features with user input masks. The height image was constructed modified height map. The pixel heights are compressed, and a triangle mesh representing the bas-relief is determined by placing a vertex at each pixel position. Most features can be preserve by proposed method, but no consideration is made for the front-to-back or overlapping relationship between different image regions.

[29] present a two-level approach for height map estimation from the rubbing images of restoring brick and stone relief. The relief is separated into low and high frequency components. The base relief of the low frequency component is estimated automatically with a partial differential equation (PDE)-based mesh deformation scheme. The high frequency detail is estimated directly from rubbing images automatically or optionally with minimal interactive processing. This method works well for reliefs based on stone rubbing images, but is unsuited to general photographs or paintings.

2.3 Stroke Segmentation

To the best of our knowledge, there is lack of study on extracting brush strokes from paintings. We give a brief overview of the work related to the relevant topics, i.e. decomposing images into layers and stroke segmentation, which are employed in our implementation. In digital image editing, layers organize images. However, scanned paintings and photographs have no such layers. Without layers, simple edits may become very challenging.

Richardt et al.[30] present an approach to produce editable vector graphics, in which the selected region is decomposed into a linear or radial gradient and the residual, background pixels. [31],[32]present two generalized layer decomposition methods, which allow pixels to have independent layer orders and layers to partially overlap each other.[33] present a layer decomposition method based on RGB-space geometry. They assume that all possible image colors are convex combinations of the palette colors. Computing the convex hull of image colors and per-pixel layer opacities is converted into a convex optimization problem. Thus, method in [33] can work well without prior knowledge of palette colors. However the proposed method simply focus on layer decomposition not stroke segmentation, how to extract the brush stroke remains a problem.

Li et al.[34] describe a method based on seed growing for brush stroke segmentation. Starting from seed coordinates, neighboring pixels are visited by exploiting a region-growing-based approach with a variable threshold, which is initialized at a predefined and automatic updated by a shape validation method. But their brush stroke segmentation is limited to finding brush strokes in Van Gogh’s paintings, and it does not support segmenting overlapped strokes.

Xu et al.[19] aims at decomposing Chinese paintings into a collection of layered brush strokes, with an assumption that at most two strokes are overlapping. However, their approach requires a good amount of prior knowledge of shape and order of strokes. The segmentation of brush strokes is based on using a brush stroke library. While our method needs no brush stroke library, and our segmentation is based on multiple layers which more than two brush strokes could overlap each others(Figure ??).

Most Stable Extremal Regions (MSERs) algorithm[35] has been proved to be a very efficient way in stroke segmentation from scene text images[36][37], and the revised version has been widely used in stroke segmentation of hand-written characters[38].

The Most Stable Extremal Regions (MSERs) algorithm[35] was used for establishing correspondence in wide-baseline stereo.[39] introduced the data structure of the component tree in it and further developed it as an efficient

segmentation approach, which prunes the component tree and selects only the regions with a stable shape within a range of level sets, see Section 5.1.

However, it is likely that MSERs may fail in segmentation with the following scenarios,

- (1) two adjacent regions with the similar intensity;
- (2) the region with a high transparency.
- (3) Moreover, like the other existing segmentation approaches, the MSERs algorithm encounters over-segmentation issue as well. To tackle these challenges, the coherent lines method [40] is introduced into MSERs in our algorithm, which both enhances the edges of strokes and preserves the completeness of strokes, see Section 5.2.

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