BOURNEMOUTH UNIVERSITY

TRANSFER DOCUMENT

From Brush Painting to Bas-relief

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September 18, 2017

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Chapter 1

INTRODUCTION

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 (Figure 1.1).Today bas-reliefs are commonly found in a variety of media in architecture, industrial design and coins. However, the production of bas-reliefs is currently a costly and time-consuming process, requiring skilled sculptors and engravers.Even with the advent of computer-driven techniques providing a foundation for automation in bas-relief, making the design of bas-relief sculptures remains largely in the hands of artists.

As an artistic form, relief spans the continuum between a 2D painting and a full 3D sculpture[1]. On this spectrum, alto-relievo (high relief) is closest to full 3D, whereas flatter artworks are described as basso-relievo (low relief, and also called bas-relief), as showed in Figure 1.1. Among all the sculpture forms, bas-relief is arguably the closest to 2D paintings, as claimed by[2] and[3].

Figure 1.1: Bas-relief

Currently, most existing bas-relief production methods focus on compressing 3D scenes/models into surfaces with a small depth[1]and[2]. This approach requires a 3D model as a starting point.

Another option is to generate bas-reliefs directly from 2D images.There have been some image based bas-relief production approaches avail able in[4][5] and [6]. These approaches almost follow the "bas-relief ambiguity"[7], that is, roughly speaking, from a frontal view the sculpture looks like a full 3D object while a side-view reveals the disproportional depth.

While most image based method are focusing on general photograph, which unsuited for specific problems for brush paintings, such as spatial occlusion (i.e. one stroke occludes other strokes in the paining to demonstrate the depth perception) and stroke transparency. A another clear shortcoming is current image based methods can't take the artistic intent into account, as all what they do is to inferring the height information from the image. Concerning reproduction or modifying of an artistic painting, it is crucial that the style of the originals is preserved, which is not considered in existing image-based methods. However, little is done in the area of bas-relief generation from artistic paintings, as maintaining the styles of the brush paintings proves much trickier than simply manipulating the height of the contour lines. In the case of bas-reliefs, although there is no 3D model available, pseudo 3D effect reflecting the style and subtlety is crucial in preserving the artistic essence.

The aim of our research is to provide the bas-relief sculptors with a new tool allowing them to convert and recompose existing brush paintings to bas-reliefs. We also argue that because traditional paintings are produced with individual strokes, '3D bas-relief strokes' will enable them to 'paint/sculpt' a bas-relief naturally, especially if they wanted to quickly convert an existing painting into a relief. With the commonly and cheaply available 3D printing facilities, there is a growing trend in the need of bas-relief art products. A brush painting can be regarded as the union of a set of hypothetical strokes by a brush [8]. Differing from the other bas-relief generation methods, our method will honor this very feature by constructing the brush strokes individually as 3D geometric entities. 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 stroke has to be faithfully extracted. Second, spatial occlusion has to be dealt with, since artists are used to depicting it through controlling the transparency of strokes as one of the art elements. Third, as an artistic tool, the generated bas-relief should be further editable allowing the artist to rearrange, tweaking and reshaping the extracted strokes.

The shape, color and opacity of a stroke vary due to the shape and firmness of the brush as well as the forces the artist imposes. Although these variables add the complexity to stroke extraction, stylized strokes often follow distinct patterns. For example, Rosemaling paintings, a typical example of brush painting popular in North Europe, is a traditional form of decorative folk art that originated in the rural valleys of Norway. The Rosemailing designs use C and S strokes, feature scroll, flowing lines, floral designs, and both subtle and vibrant colors. The brush strokes may further be viewed as graphical objects which are meaningful with respect to the objects the painting portraits. Moreover, each stroke is clearly visible due to both subtle and vibrant colors. The similar properties may be found in some Chinese brush paints. To extract the strokes from a brush painting, we need to identify and segment the overlapped strokes. We will then generate the depth map for every stroke separately using the shape from shading (SFS) technique on the opacity. All the strokes are finally merged together to yield the resulting bas-relief with the original 2D painting preserved. 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.
(2) 3D modeling of brush strokes. We develop a novel method which may entirely construct every stroke in 3D 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.

1.1 Thesis Structure

The organization of the document is as follows:

Chapter 1: Introduction. This section provides the background, the motivation and the contribution made in current research.

Chapter 2: Literature Review. This section classifies and reviews related previous works in a systematic way.

Chapter 3: Overview of proposed approach. This section explains the methodology selected and defines some basic concepts used in the research.

Chapter 4: Layer Decomposition. This section introduces concept "Layer Decomposition" in this research, which is the basis of the proposed algorithm.

Chapter 5: Extraction of Brush strokes. This section describes the proposed algorithm of brush stroke extraction.

Chapter 6: Depth map and '3D strokes'. This section shows how to generate the individual depth maps of extracted strokes.

Chapter 7: Results. This section reviews the up-to-date results based on proposed the method.

Chapter 8: Conclusions . This section concludes the progress up-to-date.

Chapter 9: Future work. This section discusses possible future work about high relief and 3D painting.

Chapter 2

LITERATURE REVIEW

2.1 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.[9] 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 . [10],[11]present two generalized layer decomposition methods, which allow pixels to have independent layer orders and layers to partially overlap each other.[12] present a layer decomposition method based on RGB-space geometry. They assume that all possible image colors are convex combinations of the paint colors. Computing the convex hull of image colors and per-pixel layer opacities is converted into a convex optimization problem. Thus, their method can work well without prior knowledge of shape and overlap of strokes.

Li et al.[13] 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.[8] aims at decomposing Chinese paintings into a collection of layered brush strokes, with an assumption that at most two strokes are overlapping. And 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 3.4).

Most Stable Extremal Regions (MSERs) algorithm[14] has been proved to be a very efficient way in stroke segmentation from scene text images[16][17], and the revised version has been widely used in stroke segmentation of handwritten characters[15].

The Most Stable Extremal Regions (MSERs) algorithm[14] was used for establishing correspondence in wide-baseline stereo.[18] 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 [32] is introduced into MSERs in our algorithm, which both enhances the edges of strokes and preserves the completeness of strokes, see Section 5.2.

2.2 Bas-Relief generation from 2D images

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

2.2.1 Gradient and intensity based methods

Wang et al.[19] demonstrate a method by constructing bas-reliefs from 2D images based on gradient operations. In their research image gradients was first calculated, then by smoothing gradients to smooth shape changes. Finally , they boost fine features by 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. By proposed algorithm most features can be preserve , but no consideration is made for the overlapping relationship between different image regions, which is not suitable for brush paintings.
[20] 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 brick or stone, but is unsuited to general photographs or brush paintings.

2.2.2 Shape from shading(SFS) based methods

Some work uses Shape from shading for generating bas-relief from 2D photograph. SFS is a relative classic way for 3D shape recovery; see Zhang's survey [21]. 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[22], (1) orthographic SFS with a far light source [23]; (2) perspective SFS with a far light source[24]; (3) perspective SFS with a point light source at the optical center[22]; (4) a generic Hamiltonian. However, SFS is an ill-posed problem. The notable difficulty in SFS is the bas-relief ambiguity[7], 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[21]; [25]; [26]; [3];

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.

2.2.3 Line drawing based methods

Rather than generating bas-relief from a photograph,some researches start with line drawings. Kolomenkin et al.[27] aims to reconstruct a model from a complex drawing that consists of many inter-related strokes.At first, they extract the curves from the image of the drawing.Then,junctions 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 [28][29][30]. 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.

But line drawing based methods are limited to using information contained in a line drawing,which is not suited for brush strokes which contain information such as color,transparency and stroke shape.

Chapter 3

EXTRACTION OF BRUSH STROKES

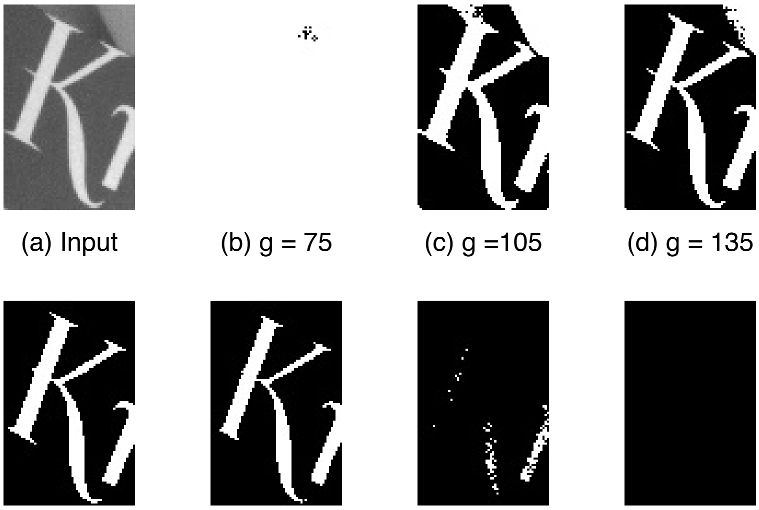
Brush strokes normally follow certain rules in a brush painting and they vary depending the type of paintings. Here we discuss how we make use of such rules. Rosemaling paintings usually use subtle and vibrant colors to enhance color contrast between overlapped strokes. As a result, the overlapped strokes tend to be classified into different layers. Extracting brush strokes within one layer is easier than directly from the input painting. We employ the Maximally Stable Extremal Regions (MSERs) proposed in [18] and [31] to extract brush strokes since it is invariant to affine intensity changes. MSERs algorithm requires a distinct difference between background and foreground while allowing a small variation of intensity within the selected stroke region. Usually, the strokes on the decomposed layers satisfy this requirement.

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 [32] is introduced into MSERs, which both enhances the edges of strokes and preserves the completeness of strokes. For completeness sake, we briefly address MSERs algorithm and then address our modification.

3.1 MSERs Algorithm

Maximally Stable Extremal Regions (MSERs) [14] can denote a set of distinguished regions that are detected in a gray scale image. All of these regions are defined by an extremal property of the intensity function in the region and on its outer boundary. MSERs have properties that form their superior performance as stable local detector. The set of MSERs is closed under continuous geometric transformations and is invariant to affine intensity changes. Furthermore MSERs are detected at different scales.

MSER requires a data structure that can be efficiently built and managed. The component tree is a structure which allows the detection of MSERs within an image and, in addition, constitutes the basis for MSER tracking. The component tree has been recently used for efficient implementation of watershed segmentation [33] .



(a) Input (b) g = 75 (c) g =105 (d) g = 135

(e) g = 165 (f) g = 195 (g) g = 225 (h) g = 255

Figure 3.1: Extreme regions based on threshold

Threshold images analyzed during creation of component tree. Figure (a) shows the considered area and figures (b) to (g) the results of thresholding this image at gray level g. The letter k is identified as MSER because the size of the connected region does not change significantly in the gray level range from 135 to 195.

The edges within the tree define an inclusion relationship between the connected regions. Thus, for a region that is the son of another region within the tree, is fulfilled. By moving in the component tree upwards, the corresponding intensity value g of the extremal regions becomes lower, which leads to increased region sizes. The root of the tree represents a region which includes all pixels of the input image . Figure 3.2 shows typical parts of the component tree created for the image shown in Figure 3.1(a).

MSERs can denote a set of distinguished regions that are detected in an intensity image. All of these regions are defined by an extremal property of the intensity function in the region and on its outer boundary, i.e. for a given extremal region S, the internal intensity is more than the intensity of boundary of S,

$$\forall p \in S, \forall q \in \partial S, \longrightarrow I(p) \geq I(q)$$

where ∂S denotes the boundary of S. Changing threshold, the extremal regions may further split or merge. The resulting extremal regions may be represented by the component tree. Accordingly, we may compute the change rate of the area of extremal region by,

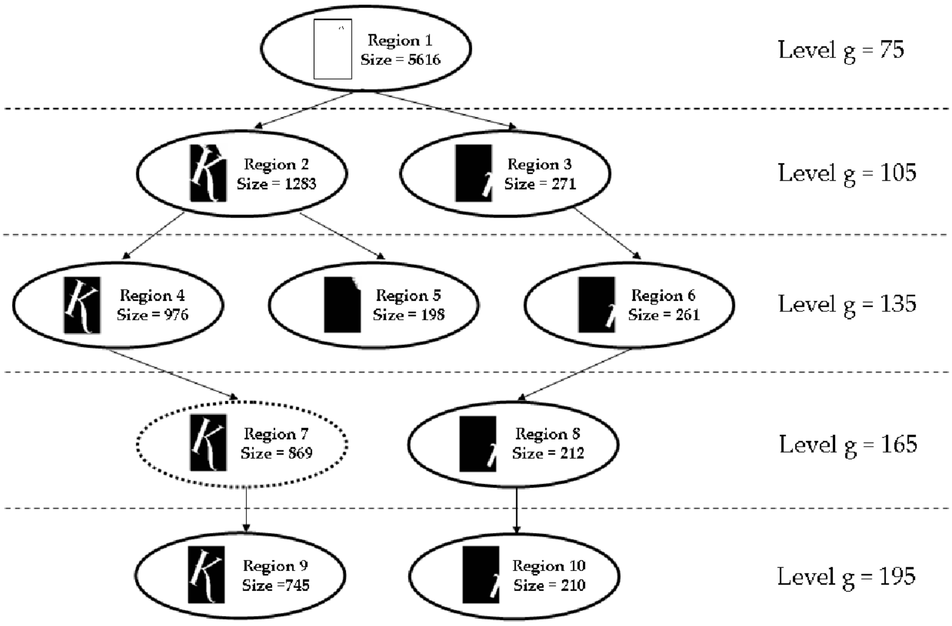


Figure 3.2: MSER tree

Parts of the created component tree for the input image. Region 7 is identified as MSER.

$$\gamma(S_i^g) = \frac{\left(\left|S_j^{g-\Delta}\right| - \left|S_k^{g+\Delta}\right|\right)}{|S_i^g|}$$

where $|.|$ denotes the cardinality, S_i^g is the i-th region which is obtained by thresholding at an intensity value g and Δ is a stability range parameter. $g-\Delta$ and $g+\Delta$ are obtained by moving upward and downward respectively in the component tree from the region S_i until a region with intensity value or is found. $\{i, j, k\}$ are the indices of nodes of the component tree. MSERs correspond to those nodes of the component tree that have a stability value γ, which is a local minimum along the path to the root of the tree.

Figure 3.3: MSERs on the intensity of image

Perform the original MSERs on the intensity of image; It is clear to see over-segmentation.

3.2 Modified MSERs Algorithm

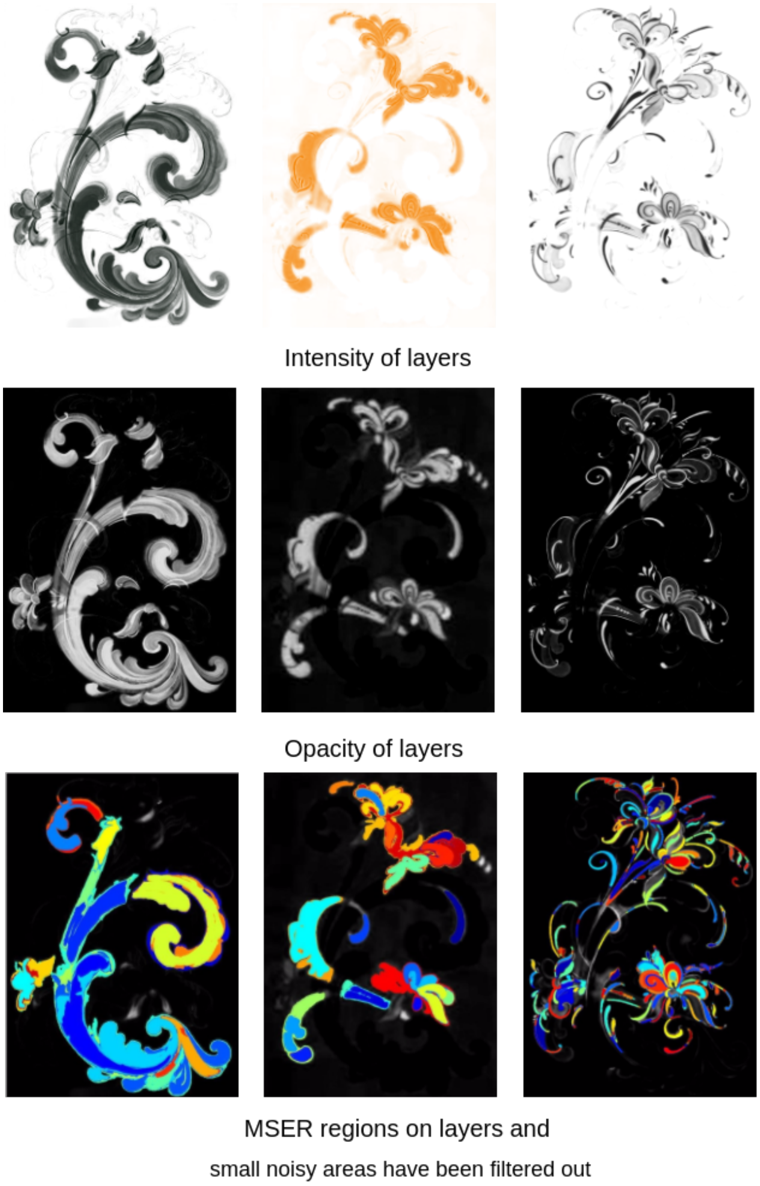


Figure 3.4: The intensity, opacity maps, and MSER regions of three layers by the modified MSERs.

In terms of the definition of the area change rate γ, MSERs may fail in segmentation with the following scenarios,
(1) the region with the intensity very close to the background;
(2) two adjacent regions with the similar intensity;
(3) the region with a very high transparency.
The opacity of the image, α, is always independent of the intensity of the image. It is likely to avoid the abovementioned scenarios if segmentation can be performed on γ. We perform the layer decomposition of Eq **??** on a brush painting and show the intensity and opacity of one layer associated with the individual histograms in Figure **??**. It can

be noted that the opacity of the layer contains richer layered details than the intensity. Moreover, Table 1 also shows that the opacity of the layers is more suitable for stroke segmentation than the intensity. The first modification is to perform MSERs on the opacity of every layer. We aim at the scenarios of two adjacent regions with the similar opacity. When the extremal region is growing up through changing threshold, it is feasible to restrict the region by introducing the coherent lines. According to the definition of the extremal region, the boundary of region S should satisfy,

$$\forall p \in S, \forall z \in \bar{S}, \forall q \in \partial S \longrightarrow I(p) \geq I(q) \text{ and } I(q) \leq I(z)$$

where $\bar{S}$ denotes the complement of S. The second modification is to simply modify the opacity of layers, that is, overlapping the coherent lines with the layer and then changing the opacity of coherent lines to the smallest value in the layer.

To deal with the over-segmentation issue, the coherent lines play an important role. Given a region S, we modify the area change rate γ as,

$$\gamma(S_i^g) = \frac{||S_j^{g-\Delta}| - |S_k^{g+\Delta}||}{|S_i^g|} + \frac{||Q_j^{g-\Delta}| - |Q_k^{g+\Delta}||}{|Q_i^g|} - (1 - \frac{|Q_i|}{|\partial S_i^g|}) \tag{3.1}$$

where Q denotes the set of pixels which stay on the coherent lines and $Q \subset \partial S$. The third modification is to take into account the change of coherent lines to the boundary of S, i.e. the third term penalizes that a small portion of the boundary ∂S is occupied by coherent lines.

Figure 3.4 shows the segmentation results by the modified MSERs, which correspond to brush strokes. It can be noted that performing MSERs on the intensity of image inevitable yields over-segmentations. Performing the modified MSERs on the opacity of layers, the strokes tend to complete and smooth within one layer. Moreover, some small regions with the distinct opacity values against neighboring areas have been filtered out.

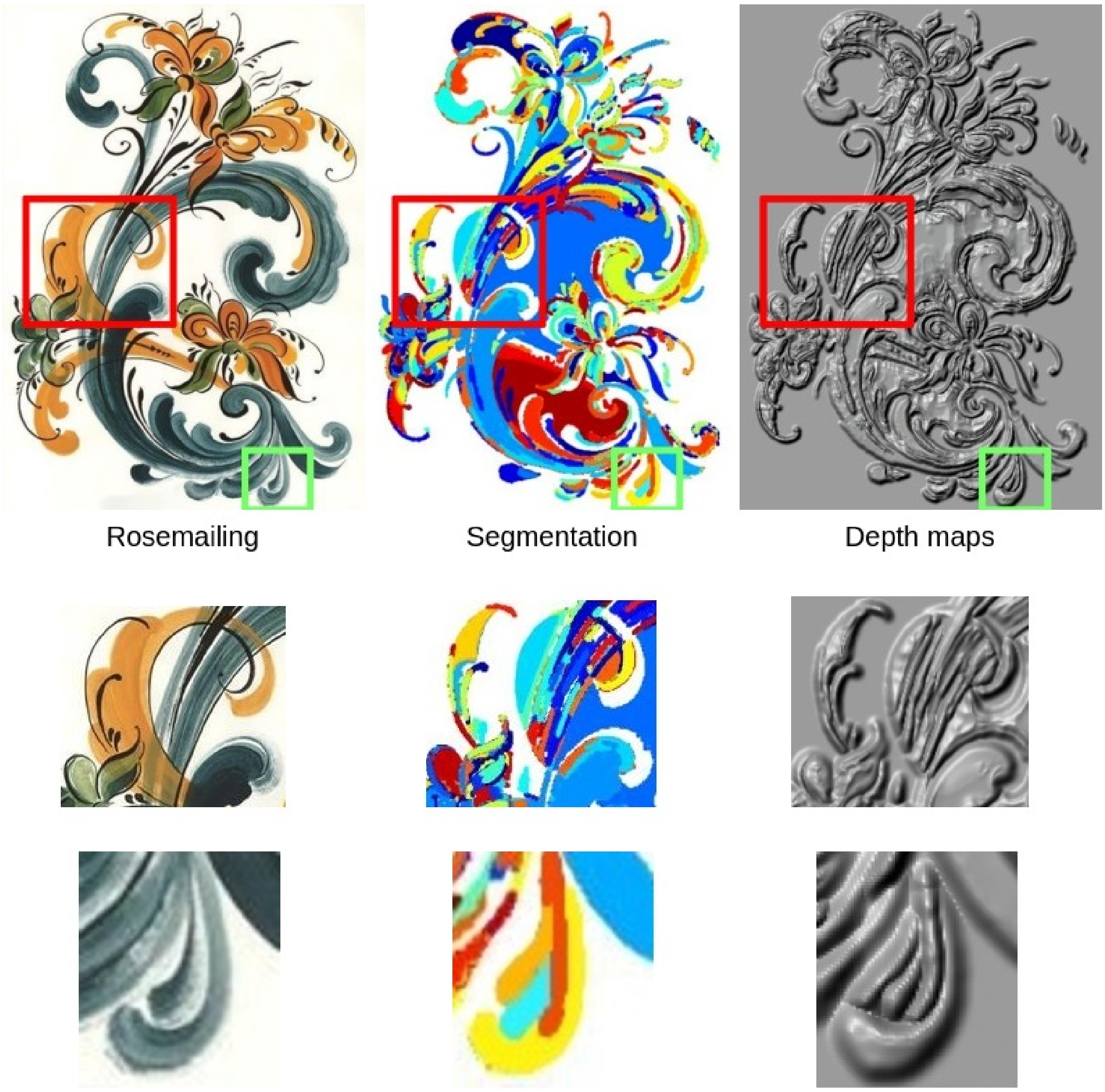


Figure 3.5: Incorrect and over segmentation

Resulting depth maps based on segmentation of image intensity. Second row shows the incorrect segmentation (brown area in Top is missed in Middle);Last shows the over-segmentation (2 patches in Top are divided into 4 parts in Middle).

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