

# AUTOMATIC GENERATION OF PENCIL SKETCH FOR 2D IMAGES

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## ABSTRACT

Non-Photo-Realistic Rendering (NPR) is becoming increasingly important research topic in computer graphics and image processing. This paper puts forward a novel method for automatically generating a pencil sketch from a real 2D color image in non-photo-realistic rendering. First of all, the edge of the color image is detected by Sobel operator. Secondly, the color image is sharpened by Unsharp Mask (USM), then color scaling is used to get an image with radial and edge details. Furthermore, the original image is divided into many meaningful regions using an efficient method of image segmentation, then the texture direction is determined by Fourier transform and shape feature. To render better effects of illumination and local texture of pencil sketch, the Line Integral Convolution (LIC) algorithm is applied and combined color scaling and white noise image. At last, the pencil sketch is created and the generation results from the superposition of the edge, the USM image and the texture. The experimental results prove that our approach could efficiently generate more obvious edge, more natural tone and more real texture than existed methods.

**Index Terms**— Non-Photo-Realistic Rendering, Pencil Sketch, USM Sharpening, Texture

## 1. INTRODUCTION

Not only photo-realistic rendering but also Non-Photo-Realistic Rendering (NPR) has become one of the most important research issue. NPR is a technique which generates pictures that have manual drawing style, but not the realistic effect as photographs. However, little attention has been given to pencil drawing. In general, the pencil sketch in NPR research can be classified into two categories: transformation from 2D images, and direct rendering of 3D scenes. So far some basic work has been done and several applied systems have been developed. There is one early 2D painting system called PencilSketch [1], which provides a mouse based virtual tablet and

inputs necessary parameters by users for interactive drawing, the system couldn't widely apply because of not automatic generation. In an observation model of pencil sketches [2] developed by Sousa and Buchanan, they scan electron microscope to investigate the real pencil sketch, then build the models of pencil and paper, which lead pencils to paint interactive drawing after users specify some parameters of these models and strokes, finally one 2D image will be converted into a pencil sketch. In addition, they have developed other 3D polygon models that could automatically render into pencil sketches for 3D scenes [1]. Currently, a new method of pencil drawings for transformation from 2D images is proposed by Mao et al [3], and then Li et al improved this approach [4, 5].

In this paper, we propose a novel method for automatically generating a pencil sketch from real 2D color images, design and realize an automatic generating system of pencil sketches, the generating result is satisfied and the generating implementation is efficient.

## 2. OUR GENERATING METHOD FOR PENCIL SKETCH

- Use Sobel operator with attenuation factor to extract the boundary  $I_{Sobel}$  of the original image  $I_{input}$  to finish outline drawing;
- Subdivide the original image into different regions  $\{S_i | i = 1, 2, \dots, N\}$  using region segmentation based on graphic theory;
- Apply Fourier transform and shape feature to determine texture direction  $I_{direction}$  of each region  $S_i$ ;
- Get  $I_{threshold}$  from the original image by color scaling, then obtain  $I_{noise}$  from  $I_{threshold}$  by white noise processing, and combine texture direction ((3)  $I_{direction}$ ) to draw the texture of pencil sketch  $I_{texture}$  by applying LIC;
- To obtain the USM image  $I_{USM}$ , do the gray scaling for the original image, which is then sharpened by Unsharp Mask and color scaling;

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- Generate the final pencil sketch  $I_{output}$  by superposition of the edge ((1)  $I_{Sobel}$ ), the USM image ((2)  $I_{USM}$ ) and the texture ((4)  $I_{texture}$ ).

### 3. OUTLINE DRAWING

In traditional painting art, painting tools generally consist of charcoal, pencil, pen and so on, which mainly express the effect by outline and lines, so outline drawing is very important during the course of pencil sketch.

In general, outline drawing needs to extract the boundary for the original image. The boundary mainly exists between object and background, which is important basis of image segmentation, texture feature and shape feature for image analysis and understanding. We apply Sobel operator to extract the boundary. For each pixel of the digital image  $f(i, j)$ , consider the weighted difference for gray scale of whose neighbors up, down, left and right, get the bigger one between horizontal difference and vertical difference or the sum of two differences as input, in order to get the effect of boundary extraction of the image.

Sobel operator is defined by equation (1):

$$S(i, j) = |s_x| + |s_y|$$

$$= |f(i-1, j+1) + 2f(i, j+1) + f(i+1, j+1) - (f(i-1, j-1) + 2f(i, j-1) + f(i+1, j-1))|$$

$$+ |f(i-1, j-1) + 2f(i-1, j) + f(i-1, j+1) - (f(i+1, j-1) + 2f(i+1, j) + f(i+1, j+1))|$$
(1)

The convolution kernels of X axis and Y axis are given by equation (2):

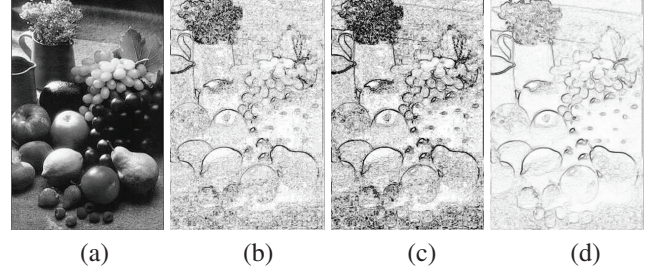
$$s_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad s_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (2)$$

In order to eliminate data overflow, retain all boundary information of the original image, extract undistorted boundary, we introduce an attenuation factor Scale, use attenuation factor to get rid of the bigger one between horizontal difference and vertical difference or the sum of two differences, which is given by the following equation (3):

$$S(i, j) = \max\{|s_x|, |s_y|\} / \text{Scale} \quad \text{or} \quad (3)$$

$$S(i, j) = (|s_x| + |s_y|) / \text{Scale}$$

In our experiment, we get the attenuation factor as 4, and do experiments with several operators above. In Fig. 1, the outline with Sobel operator is more smooth and clean, and is able to filter some noise and partial pseudo-boundary.



**Fig. 1.** Comparison of these rendering methods for contour drawing. (a) Original image [4] for our experiment, (b) Result by Neon processing, (c) Result by Roberts crossover operator, (d) Result by Sobel operator.

### 4. UNSHARP MASK PROCESSING

To sharp the original image by Unsharp Mask processing (USM), firstly smooth the original image according to filtering for high pass, furthermore, this part of smooth image is subtracted from the original image, at last, the effect of high pass is for the original image. The following equation (4) is given for 2D discrete filter of high pass.

$$g(i, j) = e^{-\frac{i^2+j^2}{2\sigma^2}} \quad (4)$$

Select the suitable  $\sigma^2$  then can design the template of Gauss filter  $w(i, j)$  based on the window of  $n \times n$ , set the function equation of the original image is  $f(i, j)$ , through the convolution operation on the image  $f(i, j)$  to get the smooth image. Set the image as  $h(i, j)$  after the smooth processing, \* is the convolution operation, the calculation method is given by equation (5):

$$h(i, j) = f(i, j) * w(i, j) = \sum_{k=0}^{m-1} \sum_{l=0}^{n-1} w(k, l) \times f(i-k, j-l) \quad (5)$$

Finally, we can get the effect of high pass with the subtract of the original image and the smooth image. Set the equation of image as  $t(i, j)$  after the filter of high pass, the subtract operation is given by equation (6):

$$t(i, j) = (1 + d) \times f(i, j) - (d - \eta) \times h(i, j) \quad (6)$$

where  $d$  is the adjusting value for the subtract of the smooth image from the original image;  $\eta$  is empirical coefficient, we define  $\eta$  as 0.3 and  $d$  as 4.0 usually in our experience. To get the better effect for the image of the filter of high pass, we make sure that the image has certain extent of smooth, and then do the color scaling after Unsharp Mask processing, which is scaled with the same proportion for three color component  $r, g, b$ .

## 5. PENCIL TEXTURE AND TEXTURE DIRECTION

### 5.1. Drawing texture leveraging LIC

Line Integral Convolution (LIC) was first proposed by Brian Cabral and Leith Leedom in SIGGRAPH 1993 [6], which is able to filter for low pass of noise texture based on the dependence of vector direction. This is due to good visual processing for the vector field, the method is widely apply in image processing, computer art and some relevant field.

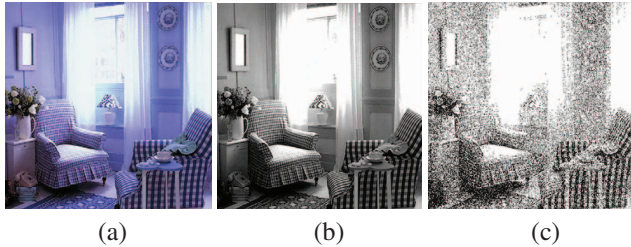
1) *Color scaling*: Before using LIC, we must get white noise image of the original image, but LIC processing is for the whole image, so we need to control the region of LIC processing. In addition, we have to retain necessary blank area to excite the imagination of appreciator. Therefore, we use color scaling to process the gray image of the original image, generally give scaling as 1.5, however, users can adjust the value in practical application.

2) *Get white noise image*: The white noise image is generated in a way that the probability a white value is set for a pixel is proportional to the intensity level of the corresponding pixel in the original image. Different from [3] and [4], we respectively process different gray-scale area of the original image, so that the result image has good sense of space with intensity comparison and good similarity with the effect of manual drawing. The generated way of white noise image is given as equation (7).

$$\begin{cases} \text{if } I_{input} \leq L_1 & I_{noise} = \begin{cases} I_{max} & \text{if } P > T_1 \\ I_{min1} & \text{otherwise} \end{cases} \\ \text{if } L_1 < I_{input} \leq L_2 & I_{noise} = \begin{cases} I_{max} & \text{if } P > T_2 \\ I_{min2} & \text{otherwise} \end{cases} \\ \text{if } I_{input} > L_2 & I_{noise} = \begin{cases} I_{max} & \text{if } P > T_3 \\ I_{min3} & \text{otherwise} \end{cases} \end{cases} \quad (7)$$

where

$$T_i = k_i(1 - I_{input}/255), \quad i = 1, 2, 3 \quad (8)$$



**Fig. 2.** (a) Original image for our experiment using proposed method in this paper, (b) Result applying color scaling for the original image, (c) Result of white noise image.

In equation (7),  $P$  is a floating-point number generated with a random function,  $I_{input}$  is gray value of input pixel,

$I_{noise}$  is output gray value,  $I_{max}$  is the maximum gray value of input pixels, which is 255 usually, and the value will possibly be smaller in practical application.  $I_{min1}$ ,  $I_{min2}$ ,  $I_{min3}$  are the minimum gray value of input pixels,  $L_1$  and  $L_2$  are two different threshold value, usually  $L_1$  is about 25,  $L_2$  is about 80, this value of  $I_{min}$  can not be 0, and can adjust its value properly. In equation (8),  $k_1$ ,  $k_2$  and  $k_3$  are three empirical values, for example, our result of the experiment suggests that  $k_1$  is 0.9,  $k_2$  and  $k_3$  are both 0.7, and users can adjust their values in practical application. Fig. 2 is the result of white noise image after threshold processing.

### 5.2. Texture Direction

Artists usually paint pencil sketches using different texture direction and intensity to express shading and texture of object for different regions. In order to generate this effect, we need to determine the texture direction of pencil sketch.

Subdivide the original image into different regions adopting the efficient algorithm of color image segmentation based on graphic theory [7], then determine the texture direction of each segmentation region.

In the original image, some regions have apparent texture direction, and some haven't. For regions with apparent texture direction, whose energy has a direction of high intensity in Fourier energy spectrum, so we are able to determine that this region whether has apparent texture direction and its specific direction. Therefore, the texture is analyzed by the method of Fourier energy spectrum. At first transform rectangular coordinates with feature of energy spectrum in the frequency field into polar coordinates  $(\theta, r)$ , then subdivide the angle into many angles  $\theta$ , and calculate the sum of  $r$ , finally get Wedge features of energy spectrum, whose equation is given as follows.

$$P(\theta) = \sum_{i=1}^n P(r_i, \theta), \quad \theta = \theta_1, \theta_2, \dots, \theta_n \quad (9)$$

In equation (9),  $r_{i+1} - r_i = W/(2n)$ ,  $\theta_{i+1} - \theta_i = \pi/n$ , where  $W$  is the width of window in the processing,  $n$  is the discrete sampling number. According to analysis of the waveform of equation (9), find the maximum value of energy, if the proportion between this energy value and the sum of energy of all directions is bigger than the threshold, then it expresses that this region has apparent texture direction, and whose texture direction is the vertical direction of this direction.

For regions without apparent texture direction, we determine its texture direction according to the shape of this region. So the moment, centroid, central moment and direction are defined [8] as follows to describe the shape of each region.

The moment of region:

$$m_{pq} = \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} i^p j^q f(i, j) \quad (10)$$



where  $i, j$  are coordinates of pixel points in the region,  $f(i, j)$  is the gray value of image region.

The coordinates of centroid:

$$x_c = \frac{m_{10}}{m_{00}} \quad y_c = \frac{m_{01}}{m_{00}} \quad (11)$$

The central moment:

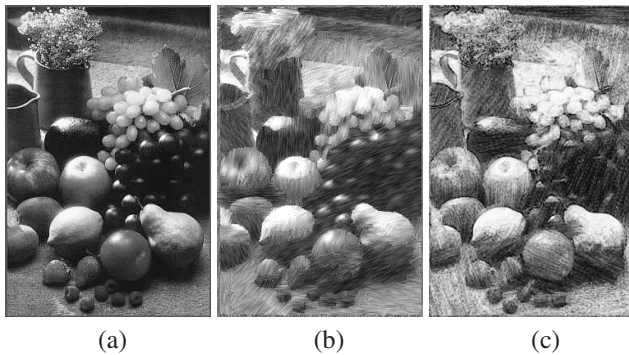
$$\mu_{pq} = \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} (i - x_c)^p (j - y_c)^q f(i, j) \quad (12)$$

The direction:

$$\theta = \frac{1}{2} \tan^{-1} \left( \frac{2\mu_{11}}{\mu_{20} - \mu_{02}} \right) \quad (13)$$

After extract the shape feature of sub region, that is calculate the moment, centroid, central moment and direction of each region, we determine the texture direction using whose direction.

## 6. EXPERIMENTAL RESULT



**Fig. 3.** (a) Original image [4] for our experiment. (b) pencil sketch result in [4]. (c) pencil sketch result generated by our method.

In order to validate the efficiency of time complexity, our system is developed on Visual C++.net, implements the automatic generation on the compatible computer with Windows XP, PIV1.7GHz and 128M memory. For a  $350 \times 280$  color image of 24-bit bmp, the system takes about 8 seconds; For a  $1024 \times 768$  2D digital image, it takes about 20 seconds, while [3] takes 20 minutes on the graphic station with PII-IXeon 933, so our method indicates more efficient than [3]. In addition, As showed in Fig. 3, the generating effect Fig. 3(b) [4] has similar style with oil paintings, for the structure of shape, it lacks line drawing of the outline of single object, the tone of objects hasn't smooth transition naturally, while our result Fig. 3(c) has similar effect with artificial style. Experimental result prove that our method could enhance the generated efficiency greatly, have more obvious edge, more natural tone and more real texture than existed methods. The whole system is more automatic and efficient.

## 7. CONCLUSION AND FUTURE WORK

We present a basic idea and algorithm of pencil sketches transformed from 2D digital images. Firstly, our system need not artificial interactive and is able to generate automatically, which can apply widely in the future; Furthermore, we proposes an efficient method of image segmentation, because image segmentation takes 90% of generation time, so our system has greatly improved in the implementation of efficiency; At last, our algorithm extracts boundary of the image to finish outline drawing, finally the result has better art effect than existed methods before. However, we also need to do other jobs of pencil sketch in the future. For instance, we need to classify those pictures for different scenes of landscape painting, still life painting and figure painting, respectively, so that generate different style of pencil sketch, and find other methods for pencil texture and outline and so on to make better similar art effect with artificial drawing.

## 8. REFERENCES

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