Enhanced LIC Pencil Filter

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Abstract
This paper proposes an extension to the existing automatic pencil drawing generation technique based on Line Integral Convolution (LIC). The original LIC pencil filter utilizes image segmentation and texture direction detection techniques for defining outlines and stroke directions, and the quality of a resulting image depends largely on the result of image segmentation. It may fail to generate a reasonable result when the segmentation result is not consistent with the structure of the input image. To solve this problem, we propose in this paper to avoid the explicit region subdivision. Instead, we divide a source image into layers of successive intensity ranges, generate a stroke image for each layer, and add them together to obtain the final pencil drawing. We also demonstrate how the enhanced LIC pencil filter can be used for processing video sequence for pencil drawing effect.

Keywords Painterly image filtering, Non-photorealistic rendering, pencil drawing, line integral convolution.

1. Introduction
In the past decade, a number of techniques have been developed to simulate traditional artistic media and styles, such as pen and ink illustration[4-7], graphite and colored pencil drawing[8-10], impressionist styles[2], paintings of various materials including oil[1], water color[3] and so on. The existing researches on painterly image generation mainly take two different approaches. The first approach is to provide physical simulation to the materials and skills, and has been mainly combined with interactive painting systems or 3D non-photorealistic rendering systems for generating realistic painterly images. The second approach is the painterly filtering, which involves taking an image and applying some kind of image processing or filtering techniques to convert it into an image of a painterly look. While many excellent painterly filtering techniques have been developed for generating brushstroke based paintings[11], relative few publications can be found on converting a source image into line stroke based drawings. In case of drawing, geometric information such as the outline of regions, the direction and shape of strokes becomes more critical, while it is usually difficult to extract such information from 2D raster images automatically. Instead of modeling line strokes geometrically, we have developed a pencil drawing filter using Line Integral Convolution (LIC), a texture based flow visualization technique[14]. The technique utilized the similarity between the appearance of LIC images and pencil strokes, and succeeded in generating line stroke like images with pixel-by-pixel image filtering. It employs image segmentation and texture analysis technique to automatically detect outlines and decide stroke orientation. Figure 1b shows a pencil drawing automatically generated from the photo in Figure 1a using LIC pencil filter.

This paper proposes an extension to the original LIC pencil filter. With the original LIC pencil filter, the source image is first segmented into different regions.
Then for each region, if it contains directional textures, the texture directions are used as the stroke directions, otherwise a randomly chosen stroke direction is assigned. We will refer to this method region based technique here after. With the region based technique, the quality of the resulting image depends largely on the result of image segmentation. Unfortunately, despite of the long history of image recognition technology, it is still difficult to find a good segmentation algorithm which can always produce regions which are consistent with the regions perceived by human eyes. Therefore the existing LIC pencil filter may fail to generate ideal results for those images where segmentation result is critical in representing the scene. Figure 2 shows an example of such failure caused by the unnecessary segmentation of the face area into small regions. To solve this problem, we propose in this paper to avoid the explicit region segmentation. Instead, we divide a source image into layers of intensity range, and define a stroke direction for each layer. Such intensity layer based technique is actually well used in real pencil drawing where artists usually render a target tone by successively adding layers of strokes. Our experiments show that the new layer based technique is particularly useful for those source images consisting of regions with continuous intensity distributions. Based on the layer based LIC pencil filter, we also present a new technique for converting a video sequence into a pencil drawing like animation.

The remainder of this paper is organized as the follows: Section 2 gives the background of our research. Section 2.1 is a short survey on related work. Section 2.2 introduces the original LIC pencil filter. Section 3 presents the algorithm of the new intensity layer based LIC pencil filter and Section 4 describes how to automatically divide the source image into different intensity layers. The extension to video sequence is described in Section 5. Section 6 concludes the paper.

2. Background

2.1 Related work

Pencil drawing has been an important topic since the beginning of painterly image generation research history. In an early 2D painting system called PencilSketch[13], a mouse based virtual tablet is provided for allowing users to interactively specify a set of parameters, such as the hardness of pencil, the pressure applied to a pencil, and the orientations of strokes. Recently, Sousa and Buchanan developed several pencil drawing rendering techniques based on an observation model of pencil drawings[9,10]. They built the models of pencil, paper and how lead pencils interact with drawing paper through a careful investigation of the real pencil drawings using scanning electron microscope. When the parameters of those models and the strokes are specified, a 2D image can be converted into a pencil drawing[9]. 3D polygon models can be automatically rendered into pencil drawings by referring to the tone value lookup table for the parameter values of the models[10]. Takagi and Fujishiro proposed to model the paper micro-structure and color pigment distribution as 3D volume data and use volume ray-tracing for rendering color pencil drawings[8]. Other existing painterly image generation techniques closely related with our work are probably those successful work on pen–and-ink illustrations[4-7]. In their interactive systems, pen-and-ink illustrations can be generated either from 3D models[6] or 2D images[7] by using a set of pre-stored stroke textures. The largest difference between our technique and all these existing techniques is that our technique can generate a pencil drawing from a source image in a completely automatic way while all these existing techniques rely, to certain extent, on user interventions, for specifying the attributes and directions of strokes. Several commercial packages provide some filters for creating pencil drawing effects. For example, Jasc Paint Shop Pro® software supports a black pencil filter. However, to obtain a satisfactory result with those filters, a user usually needs to combine the effects of many other filters and explore the best generation process experimentally through trial and error for many times.
2. LIC pencil filter

Line Integral Convolution (LIC) is a texture based vector field visualization technique[14]. As shown in Figure 3, it takes a 2D vector field and a white noise image as the input, and generates an image which has been smeared out in the direction of the vector field through the convolution of the white noise and the low-pass filter kernels defined on the local streamline of the vector filed. The idea of using LIC for pencil drawing generation was inspired by the visual similarity of LIC images and pencil drawings. As an LIC image is obtained by low-pass filtering a white noise along the local streamlines of a vector field, we can observe the traces of streamlines along which intensity varies randomly. Such traces have a similar appearance of pencil strokes where the variance of intensity is caused by the interaction of lead material and the roughness of paper surface. Figure 4 depicts the algorithm of original LIC pencil filter. It converts a 2D source image into a pencil drawing in the following seven steps:

1. Generate a white noise(Figure 4(b)) from the source image(Figure 4(a)).
2. Segment the input image(Figure 4(a)) into different regions(Figure 4(c)).
3. Extract region boundary(Figure 4(d)).
4. Generate the vector field (Figure 4(e)) representing the orientation of strokes.
5. Generate stroke image (Figure 4(f)) by applying LIC to the white noise(Figure 4(b)) and the vector field(Figure 4(e)).
6. Add the boundary (Figure 4(d)) to obtain the drawing with outlines(Figure 4(g)).
7. Composite the resulting image (Figure 4(g)) with the paper sample (Figure 4(h)) to obtain the finished pencil drawing(Figure 4(i)).

We can easily change the appearance of the pencil drawing through adjusting some parameters of LIC. For example, varying the length of the line integral convolution kernel visually changes the length of strokes and adjusting the granularity of white noise changes the width of strokes. To match the tone between the source image and the resulting pencil drawing, 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 source image. In step 2, a texture based segmentation technique is used to segment the source image into different regions and each region is assigned with a unique and randomly chosen stroke direction. At Step 4, a Fourier analysis technique is employed to extract the directions of texture at each pixel[16]. If the pixel is not a part of a directional texture, then the stroke direction assigned to the region containing the pixel is used as the stroke direction at the pixel. Such approach is based on the consideration that a well used technique in real pencil drawing for conveying the 3D shapes of objects and spatial relationship among different objects is to emphasize the boundary between different regions by changing the appearance of strokes for different regions. As we mentioned in Section 1, however, this previous approach fails to produce ideal result due to the limitation of current automatic image segmentation technique.
Figure 5  Algorithm of intensity layer based LIC pencil filter
3. Intensity layer based LIC pencil filter

In this paper, we propose a new technique which avoids using image segmentation, but divides the source image into different intensity layers. We generate stroke image for each intensity layer and then add them together to obtain the final pencil drawing. As shown in Figure 5, the new layer based LIC pencil filter converts a source image into a pencil drawing in the following 5 steps:

1. Divide the source image into different intensity layers. In real pencil drawing, artists usually use quantized levels of tones instead of continuous one to make the resulting drawing more illustrative and expressive. To simulate such effect, we select the average intensity of each layer as the representative intensity value for the layer, and convert each layer into a binary image by change all non white pixel into the representative value(Figure 5(b)(c)(d)).

2. For all layers except for the darkest layer, generate their stroke images with LIC pencil filter. We use one stroke direction for each layer(Figure 5(e)). By varying the stroke direction for different layers, we can achieve cross-hatching effect.

3. Since the darkest layer is usually most important for representing the texture as well as the shape of an object, we use the same method as in the original LIC pencil filter for defining the stroke direction for this layer. In other words, we first detect texture direction. If texture direction is detected, then it is used as the stroke direction. Otherwise a given direction is used for the whole layer. Also we use a mask image obtained by binarizing the intensity value of the layer to clip the resulting stroke image so as to obtain regions of sharp boundaries (Figure 5(f)).

4. Extract outlines by applying edge detection algorithm to the source image. Since all strokes on a layer are in the same direction, outlines become more important in depicting the structure of a scene. We enhance the detected edges image by darken those pixels with it’s value exceeds a given threshold(Figure 5(g)).

5. Add all layers together and adjust the resulting image with the paper model to obtain the final pencil drawing( Figure 5(h)).

Comparing Figure 5(h) and Figure 2(b), we can find that the new layer based technique can produce better result than the original region based technique. In this example, the source image is divided into three layers: white, gray and dark. Strokes are oriented to have an angle of 60° from X-axis on the gray layer. On the dark layer, strokes are oriented in the direction of hair texture. Figure 6 shows another result generated with the enhanced LIC pencil filter.

4. Automatic layer subdivision

To achieve realistic pencil drawing effect with our new layer based technique, the intensity layers should be consistent with the layers perceived by human eyes. An ideal layer subdivision usually corresponds to a clustering of pixels, with lowest intensity deviation or continuous intensity distribution within each cluster, and large deviation or abrupt intensity change among different clusters. Although it might be possible to employ some classic image clustering technique, we propose an intuitive method to obtain such a layer subdivision automatically. Our algorithm starts with sorting the pixels of the source image according to their intensity values. Then as shown in Figure 10, we generate a 2D graph with X axis representing pixels in increasing order of intensity value and Y axis representing intensity values of the pixels. We call this graph intensity distribution graph. Obviously the pixels within an interval of constant gradient on the intensity distribution graph should belong to the same layer. Therefore we find all positions on the intensity distribution graph where gradient changes abruptly, and use the intensity values there as the thresholds to divide source image into different layers. To find these
positions, we keep comparing the gradient at adjacent pixels on the intensity distribution graph. If the difference of gradient at two adjacent pixels exceeds a user given threshold, then the position is selected. In our current implementation, we only support three layers. If more than two positions are selected, we will only choose the two with most abrupt gradient change. On the other hand, if less than two positions are selected, we lower the threshold to have more candidates. Figure 7 uses an example to depict our automatic layer subdivision method. Figure 7(a) is the source image, Figure 7(b) is its intensity distribution graph and it is automatically divided into three parts of relative constant gradient. These three parts correspond to the three layers in pencil drawing generation. Figure 7(c) shows the image with the three automatically subdivided intensity layers and the resulting pencil drawing. For comparison, Figure 7(d) shows the result of dividing intensity range equally into three parts. Obviously the proposed method produces more natural results where the bright layer approximately correspond to the back ground, and the other two layers correspond to subjects.

5. Extension to video sequence

Featuring as an automatic approach, our LIC pencil filter has very high potential to be extended for processing video sequence to have pencil drawing effect. However, simply applying LIC pencil filter to each frame of a source video sequence can not produce painterly animation sequence of reasonable quality because of the temporal aliasing caused by the high frequency in LIC images and the lack of frame-to-frame coherence. In this section we present several methods to eliminate those artifacts.
Our technique is based on the new intensity layer based LIC pencil filter. For each frame of the source video sequence, we divide it into 3 layers: bright, gray and dark. To eliminate the high frequency in each frame, we obtain the pencil drawing effect of the gray layer by applying Gaussian low-pass filtering instead of LIC filtering. Such kind of low-pass filtering actually produces an effect similar to that achieved with the so-called “erasing” technique, which is usually used for producing a soft appearance of smooth and continuous tones without showing individual strokes in real pencil drawing[15]. The dark layer is important for emphasizing the texture and shading of objects, which is actually the only information providing frame-to-frame coherence. We process the dark layer in the same way as described in Section 3. That is, if a directional texture is detected, the texture direction is used as the stroke direction, otherwise a user specified direction is used for the whole layer. The resulting LIC image is further masked to have a sharp boundary.

Figure 8  Pixels used in temporal low-pass filtering

To eliminate the temporal aliasing artifact, we need to perform low-pass filtering in temporal dimension. A naïve but well used technique is to treat the whole video sequence as a 3D image and low-pass filter it using a filter kernel of 3D local support window. Such kind of low-pass filtering, however, can neutralize the LIC low-pass filtering effect along stroke directions, which is required for simulating the appearance of pencil drawing. To avoid this problem, we propose to perform temporal low-pass filtering along the stroke directions at adjacent frames. As shown in Figure 8, assuming we are processing the pixel \( P_y^t \) at frame \( t \), we consider \( P_y^t \) and the two corresponding pixels \( P_{y+1}^{t-1}, P_{y+1}^{t+1} \) in its adjacent frames \( t-1 \) and \( t \). The low-pass filtered value of \( P_y^t \) is obtained as the weighted average of the 9 pixels --- \( P_{y-1}^{t-1}, P_{y}^{t-1}, P_{y}^{t+1}, P_{y+1}^{t+1} \) and the two adjacent pixels in the stroke directions of \( P_{y-1}^{t-1}, P_{y}^{t-1}, P_{y}^{t+1} \).

See the attached video sequences for the result of our technique.

6. Conclusions

We presented an extension to the existing LIC based pencil filter. The new intensity layer based LIC pencil filter has been implemented as a windows application using Visual C++ programming language. The new algorithm is also much faster than the existing one. The existing LIC pencil filter took about 10 minutes to generate an image of size 516 * 516 on a Pentium III PC and the image segmentation was the most time consuming part of the algorithm. By avoiding image segmentation, the enhanced LIC pencil filter can generate an image of the same size in about 20 seconds. We also demonstrated that how the new filter can be used for converting a video sequence into a pencil drawing like animation. The major future research directions include the further improvement of animation generation technique, extension to colored pencil drawing and application to non-photorealistic rendering of 3D models and scenes.

References


