Fast Generation of Various Painterly Style Images Based on Scalable Poisson Disk Pre-Sampling Technique

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(a) Input image (b) Watercolor painting (c) Oil painting (d) Colored paper mosaic (e) Pointillistic painting

Fig. 1. Various painterly style images generated by our proposed system

***Abstract*— We present a fast system for generating various painterly style images automatically from input images using a scalable Poisson disk pre-sampling technique. We developed a pre-sampling approach for drastically fast generation of artistic images. Watercolor painting, oil painting, colored paper mosaic and pointillistic painting can be generated by the proposed method.**

***Keywords*— Non-photorealistic Rendering; Painterly Rendering:**

I. Introduction

Techniques to generate non-photorealistic images such as oil painting and illustrations from 2D image including photograph as an input are called non-photorealistic rendering (NPR). Since Haeberli [1] has proposed its basic idea on generating painterly style images by stroke composition, many researches have been done on this area. We have been developing NPR methods [6] [7]. Most of conventional methods including our methods are dedicated to a specific painterly style. A system, which generates variation of painterly style images from an input with lower computational time, is desired. Then, the user can convert input images into nonphotorealistic images easily.

There have been proposed a couple of methods which generated various kinds of painterly style images [3] [4], however, they took several tens of seconds to minutes for generating megapixel images. Besides, their methods are not so much flexible to adjust visual effects to painterly styles according to user's preference.

In this paper, we propose a system for generating various painterly style images from 2D image by integrating and unifying several NPR methods we proposed so far. We present a drastically fast system that generates multi-painterly style images according to the user's preference.

II. Previous Work

Hays and Essa [3] and Johan, et al. [4] proposed methods which generate various kinds of painterly style images, but these methods are too slow. Hays and Essa reported that the computation time of a generated 1,000 × 1,000 pixel image is 80~300 seconds. Johan, et al. proposed a method for generating various artistic images based on Voronoi diagram, whose computation time of a 512 pixel image took for 5.6 seconds. Their method is considered to require much more computation time for image with rendering and a large number of pixels. They generate variation of painterly styles only by adjusting rendering parameters, for instances, stroke color, texture, and size. However, they do not handle to express variation of painting materials, as well as commonly used painting techniques such as optical mixture, halo effect, and so on.

Considering such painting materials and techniques, we have already developed generation methods of various kinds of painterly style images [6] [7]. But, each of these methods was dedicated to one specific painterly style. Fortunately, all of our methods adopted scalable Poisson disk sampling technique (hereinafter, SPDS in short), which is powerful to generate various kinds of painterly style images. SPDS technique samples input images by placing disks whose radii are the same, or different. The radii of disks are corresponding to paintbrushes. However, SPDS technique is too slow, because it samples a canvas by placing disks randomly but avoiding overlapping them.

III. System Design

We propose a system which consists of three processes: sampling, stroke composition and visual effects as shown in Fig. 2. In order to realize the system, we develop a fast SPDS technique. We also integrate and unify our previous methods to generate various kinds of painterly style images from 2D image as an input.

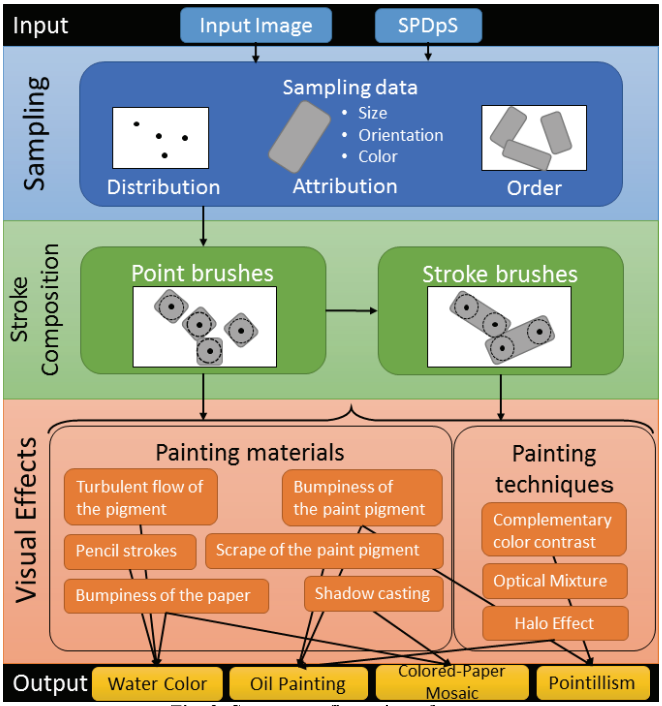


Fig. 2. System configuration of our system

In sampling process, sampling data are determined such as disk sampling distribution, disk attributions (size, orientation, color) and sampling order of the disks. The base of sampling data is determined by SPDS technique. However, SPDS technique is too slow to sample a canvas uniformly and randomly, because SPDS is based on 'darts throwing' algorithm. We accelerate the SPDS technique by pre-computation. This technique is called as scalable Poisson disk pre-sampling technique (SPDpS, in short). Sampling data are generated by using the SPDpS technique and information obtained from input image such as ETF (edge tangent flow) and edges.

In stroke composition process, both point and stroke brushes are composed. Point brush is a very short stroke, and its shape is quadrate or circular. Point brush is generated from a sampled disk directly. Point brushes are used in colored paper mosaic and pointillistic painting. Stroke brush is composed by connecting two disks which are located nearby and are similar colored. Stroke brushes are dominant to express various kinds of painterly style images such as oil painting and watercolor painting. Our system can control which types of brushes will be mainly utilized according to user's preference.

In visual effect process, we provide nine visual effects regarding both painting materials and techniques as shown in Fig. 2. Especially, stroke composition emphasizes visual effects. Details are described at Section IV.C.

IV. Proposed Method

The method for stroke composition is based on Haeberli's model, and proposed method classified this model. The model generates images with a hand-crafted look by placing brush stroke textures on a canvas. Proposed method consists of three processes, sampling, stroke composition and visual effects.

A. Sampling

1) Scalable Poisson Disk Pre-sampling Technique.

We propose a unified and fast system for generating various styles of painting images by using pre-computed SPDS technique. SPDS technique is an extended technique of hierarchical Poisson disk sampling technique (HPDS, in short) [5]. HPDS technique places disks randomly but uniformly, where the radii of all the disks are the same. SPDS technique first places large disks, then places disks gradually reducing their radii. Once disks are placed, their positions and radii are not altered. Although SPDS technique is quite resemble to HPDS but different, acceleration algorithms for HPDS technique are not applicable to SPDS technique. Therefore, we realize speeding up by using pre-computational approach. This method is called scalable Poisson disk pre-sampling (SPDpS) technique. We explain the algorithm of SPDpS technique below.

A disk, radius $r = r_{max}$, is sampled at random on the canvas. A set of disks already sampled is defined as $\{S_k\}$, and next sampling point is defined as S_j. The radii of the arbitrary point $S_i \in \{S_k\}$that already sampled and the point S_j are defined as r_i, r_j accordingly. Further, the distance between S_i and S_j is defined as d_{ij}. Meanwhile, if a case is $d_{ij} \geq \alpha(r_i + r_j)$, it is possible to place the point S_j , and if the case is $d_{ij} < \alpha(r_i + r_j)$, it is impossible to place the point S_j. However, with above conditions, in case the value of a coefficient α is low, a small disk is completely comprehended by a larger disk. No small disk is needed in large disk. And it may detract visual effect. To avoid this artifact, we added another criterion. If the case is $d_{ij} < r_i$, no disk is placed. If this procedure continues to fail many times (this limitation number is called n), which means that very few spaces are left. Then, the radius r of disks is reduced by Δr pixels (including already placed disks). This algorithm is recurred until radius r of disks become equal to r_{min}. SPDS technique varies the radii, but the radii of already placed disks are not altered. Fig. 3 shows the difference between HPDS and SPDS techniques.

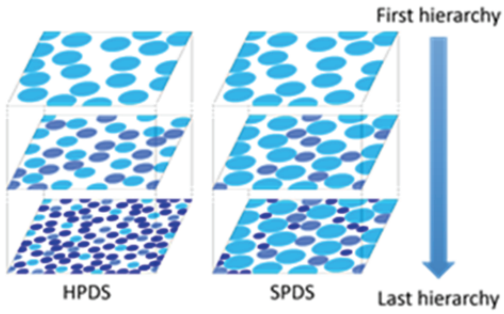


Fig. 3. Difference between HPDS and SPDS

2) Sampling Data Generation

The sampling data are results of SPDpS technique, which consists of distribution of disks, their attributions (color, size, orientation) and sampling order of disks. In artistic images, it is common that edges are emphasized and nearby regions with similar colors are drawn with one stroke. Thus, we re-sample fraction of pre-sampled scalable Poisson disks to avoid edges by referring edge information obtained from input image.

First, the disks on edges are erased from the disk placement results of SPDpS technique. Note that disk placement by SPDpS technique is calculated in advance without considering any edges. Next, a new disk is sampled within the bounding rectangle of the erased disk. Here, the disks in a square with black line in Fig. 4 are candidate disks $\{S_k\}$ for re-sampling. In Fig. 4, the disk with dotted red line on the left is located on the edge and is the target of erasing. The disks with red solid line on the right are new resampled disks.

Distribution: Determined by re-sampling results of scalable Poisson disks mentioned above.

Attribution:

Color: RGB color of input image that corresponds to the center of the coordinates of the disk of re-calculated SPDpS distribution.

Orientation: The colored paper texture is randomly rotated. The orientation is determined by applying the ETF (edge tangent flow) for water color, oil painting and pointillistic painting, since strokes should flow along the edges of the motif.

Size: Determined by the radius of the each Poisson disk.

Order: The order of the rendering textures is determined by the SPDpS technique. Thus, lager textures are placed before smaller ones. This process looks similar to actual painting process.

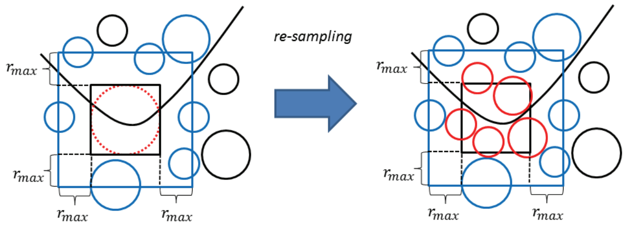


Fig. 4. Example of re-sampling of disks near the edge

B. Stroke Composition

1) Generation of Point Brush and Stroke Brush

In this section, we describe how to generate point brushes and stroke brushes from sampling data.

Point brush generation: Point brushes can be generated by using sampling data as described in Section □.A.2).

Stroke brush generation: Each disk is connected to its nearest neighboring disk whose size and color is quite similar, whose distance is smaller, and whose ETF is similar to the direction vector from one disk to another disk. Stroke brushes are generated by following steps.

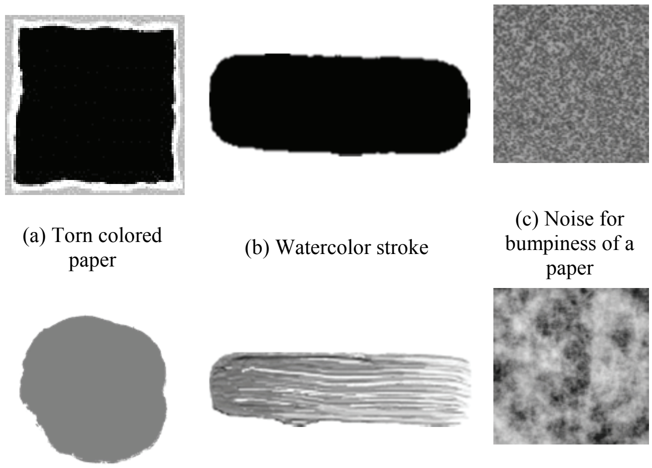
Step 1 Select one disk from all the disks arranged by SPDS technique. Then, regard it as the target disk. Other disks are called as 'listed disks'.

Step 2 Using the target disk and a disk from 'listed disks' (tentative disk), calculate following five metrics: (1) the Euclidean distance between center of both disks, (2) the radii difference, (3) the difference of center pixels colors, (4) the luminance gradient of the center pixels, and (5) the color difference accumulated from the difference calculation between the center pixel of the target disk and the pixel on the line between the target disk and a tentative disk scanned one by one. Judge if values of (1) - (5) are more than the thresholds d, Δr, t, θ, t' respectively. Eliminate the tentative disk from 'listed disks' if one or more values out of five metrics is more than the threshold.

Step 3 Choose a disk whose Euclidean distance is closest to the target disk from the 'listed disks' remaining after Step 2. The candidate disk is connected to the target disk and composed a stroke brush. Map a stroke texture on it. Proceed to Step 4. In the case of no candidate disk, judge it as a point stroke, and map a point texture on the disk, and go back to Step 1.

Step 4 Go back to Step 1 if the number of times of drawing between the target disk and the candidate disk exceeds a threshold m. If it is below m, judge the candidate disk as a target disk and go back to Step 2.

The stroke texture as shown in Fig.5 (a), (b), (d), (e) are rendered at the position determined above.



(a) Torn colored paper

(b) Watercolor stroke

(c) Noise for bumpiness of a paper

(d) Stroke for pointillistic painting

(e) Oil painting stroke

(f) Noise for turbulent flow

Fig. 5. Stroke and noise textures

2) Implementation Issues for Fast Stroke Brush Generation

According to the algorithm described in Section □.B.1), all the sampled disks except the target disk (we call these disks as 'listed disks') are tested whether they satisfy five metrics or not. Finally, the candidate disk is determined from 'listed disks'. This procedure is applied to 'listed disks', so it is tedious, not effective.

We introduce a new search strategy to reduce the number of disks to be evaluated by five metrics. A canvas is subdivided into small regions. Each region is called 'a small area'. First, we seek a disk from all the disks in the small area where the target disk belongs to. If five metrics are calculated, and the disk satisfies conditions, the disk is decided as a candidate disk of the target disk. These two disks compose a stroke. If there are no disks satisfy the conditions, search areas are expanded to its adjacent 8 small areas. Repeat this procedure until the candidate disk is determined.

Because the number of disks to be evaluated as candidate disks is greatly decreased, this search strategy is very effective to compose strokes.

C. Visual Effects

In visual effects process, the composited strokes result is emphasized with effects of painting materials or techniques. We developed nine techniques to realize these effects.

1) Effects Derived from Painting Materials

(1) Bumpiness of the paper

The bumpiness of the paper effects fluid flow or visual of torn colored paper. We synthesis noise texture (Fig. 5 (c)) on the composed stroke image.

(2) Turbulent flow of the pigment

In wet-on-wet painting, the color of the pigment runs. In order to realize the effect of turbulent flow, the texture shown in Fig. 5 (f) is provided and synthesized.

(3) Pencil strokes remaining on a canvas

In order to represent pencil strokes remaining on a canvas, edges are extracted from the input image by applying the Laplacian filter, and are synthesized.

(4) Shadow casting

In case of colored paper mosaic, for example, the actual work using thick colored paper has transparent shadow around a piece of torn colored paper. A shadow-casting effect is expressed by placing the texture initiated shadow of the torn colored paper, under it.

(5) Scrape of the paint pigment

Looking at an actual oil painting stroke, we notice that it is thick at the beginning and gradually scrapes. To express these effects, we provide a texture as shown in Fig. 5 (e), adjusted its alpha value to gradually decrease along its brush stroke.

(6) Bumpiness of the paint pigment

To express bumpiness of the paint, we applied emboss filter to the rendered strokes.

2) Effects Derived from Painting Techniques

(7) Optical mixture

Juxtaposed vivid color dots cause similar spectra of colors because the additive color mixtures on a retina blend these dots into one color. We achieve the optical mixture effect by error diffusion technique efficiently, which relies on randomly placed Poisson disks. We use Hausner's technique [2] with modification.

(8) Complementary color contrast

This visual effect generates very brilliant color contrast by placing two or more complementary colors side by side. It is used to express shading. First, we generate stippling by altering the radius r_i of Poisson disks depending on luminance l_i of input image at the sampling point i as follows:

$$r_i = \frac{255 - l_i}{255} \times (r_{max} - r_{min}) + r_{min} \qquad (1)$$

Next, complementary colors of each point of stippling are calculated by using RYB color wheel.

(9) Halo effect

To generate halo, we use modified unsharp mask (MUM, in short). MUM U_i at pixel i is expressed as follows:

$$U_i = A \cdot \left(1 - \frac{D_i}{s}\right) \cdot B \cdot \frac{1}{\sqrt{\pi\sigma^2}} exp\left(-\frac{(I_i - \mu)^2}{2\sigma^2}\right) \cdot (I_i - G_i) \qquad (2)$$

Here, A is constant for tuning effect, D_i is a distance map obtained by Canny's method, s is kernel size of Gaussian blur, B =100, expectation μ=127, variance σ=40, I_i is a luminance at pixel i, G_i is a low frequency component obtained by Gaussian blur.

3) Effects Derived from Painting Materials

In our system, we can generate multiple painterly style images by combining several visual effects according to each artistic style. We provide templates to generate watercolor, oil painting, colored paper mosaic and pointillistic painting as shown in Fig. 2.

Watercolor: (1) Bumpiness of the paper, (2) Turbulent flow of the pigment and (3) Pencil strokes remaining on a canvas.

Oil painting: (5) Scrape of the paint pigment, (6) Bumpiness of the paint pigment and (9) Halo effect.

Colored paper mosaic: (1) Bumpiness of the paper and (4) Shadow casting.

Pointillistic painting: (6) Bumpiness of the paint pigment, (7) Optical mixture, (8) Complementary color contrast and (9) Halo effect.

It is also possible to originate other combinations of our visual effects according to user's preference.

V. RESULTS

Figs. 1(b)~(e) show the generated different painterly style images by our system from an input as shown in Fig. 1(a). Fig. 1(b) is a watercolor-like image, (c) oil painting, (d) colored paper mosaic, and (e) pointillistic painting, respectively. As shown in Fig. 1, our system is able to generate various artistic style images.

We measured the computational time of both sampling and stroke composition processes of proposed SPDpS technique and conventional SPDS technique. We tested on a standard PC with a 2.5GHz Intel Core i5 CPU and 4GB memory. The input image size was 2048×2048 pixels. Fig. 6 shows computational time of watercolor painting, oil painting, colored paper mosaic, and pointillistic painting. SPDpS technique was much faster than conventional SPDS technique by about 164.3, 64.9, 17.6, 80.7 times, respectively.

The computational time of visual effects process by the conventional SPDS technique is almost same as proposed SPDpS technique. It is about 2~5 seconds.

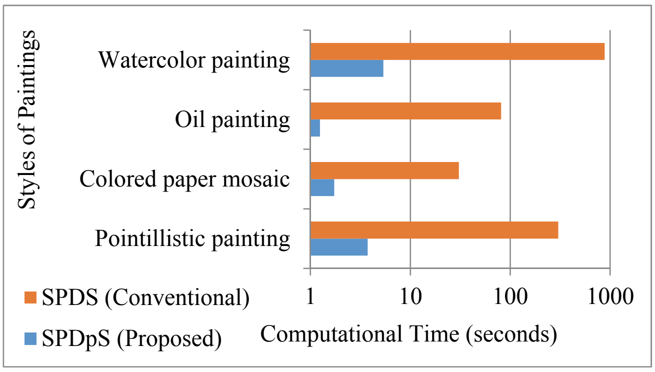


Fig. 6. Computational time of SPDS and SPDpS techniques in sampling and stroke composition process

VI. CONCLUSIONS

We have proposed a fast generation system for various painting style images by using SPDpS technique. We have shown that our proposed system has drastically shortened the time required for the process.

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