

# The Droplet Virtual Brush for Chinese Calligraphic Character Modeling

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## Abstract

*This paper proposes a virtual brush model based on droplet operation and its application on retrieving character outlines and character modeling in Chinese calligraphy style. In the proposed approach, a virtual brush model based on droplet operation is applied to produce vivid character outlines. The droplet model helps to compute stroke area with well-defined geometry information and leads to the feasibility to retrieve the outlines of characters with well-defined geometry representation. Further more, the variations of the model can express various Chinese brush styles, so by using the droplet model, we successfully overcome the poor expressive ability of the previous curve-offset method. The complex evaluation of stroke area based on physical solid-model brush is also eliminated since the simplicity of the model.*

## 1. Introduction

Numerous calligraphers have been producing countless of masterpieces since Chinese characters appeared. The hair bristle brush, which has long, starched natural bristles narrowing to a pointed tip, is convenient to use and has its special expressive ability. This has also imposed difficulties to its simulation and retrieving by computer. Design of Chinese character fonts or computing the outlines of the characters in beautiful calligraphy styles has thus attracted many researches.

### 1.1. Related Works

Simulations of Chinese calligraphy can be best described in terms of brush sweeps along curve trajectories while the brush shapes changing dynamically. Designing calligraphic style Chinese characters in terms of brush sweeps is quite natural since it simulates the way of human writing characters. Varieties of brush models have been built by many researches. One of the earliest attempts is that of Strassmann's[1]. He actually simulated the behavior of a brush with wet paint on paper and the proposed approach did not suit for font design. Wong and Ip [2] simulated the physical process of brush stroke creation using a parameterized model which captures the

writing brush's 3D geometric parameters, the brush hair properties and the variations of ink deposition along a stroke trajectory. Shamir and Rappoport introduced a parametric method to compactly represent existing outline-based oriental fonts[3]. Wong and Ip developed a fractal-based outline font technology which is able to capture the outline characteristics of calligraphy writing [4]. A most recent approach is that of Xu and Tang's[5]. In this model, clusters of hairs are represented as solid models and the imitation of the calligraphy includes some geometry operations on the model. The previous virtual brush models are all designed as some kind of soft brushes and cannot express various Chinese calligraphy effects, e.g, the effect of dry brush with stroke forks.

In traditional virtual brush model, the tangent area between the brush and the paper is computed pixel by pixel. Though powerful in simulating the actual dry-brush effect, while applied in retrieving of character outlines, this kind of brush model is inappropriate because it's too concerned with detail and the tangent area computed is lack of geometry information. And the approach in model [4], inherently an image recognition approach, is bound to encounter the dilemma when dealing with the dry stroke area. Figure 1 shows such a case.

### 1.2. Overview of the Droplet Model

By omitting some of the minor details, the proposed parameterized physical brush model has actually enhanced the traditional "soft brush" model by introducing a novel stroke model called droplet. This model, discussed in detail in section 2, can produce the stroke boundary with well-defined geometry information,

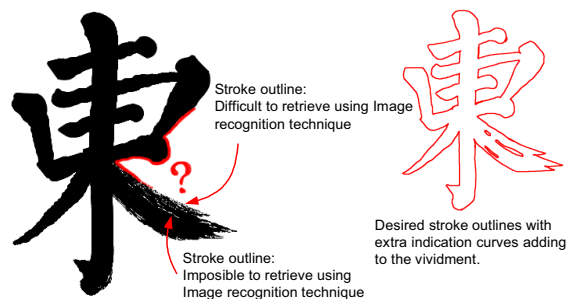


Figure 1. It is difficult to retrieve the outline of the dry strokes and impossible to get the indication curves as the desired results shown on the right in red.

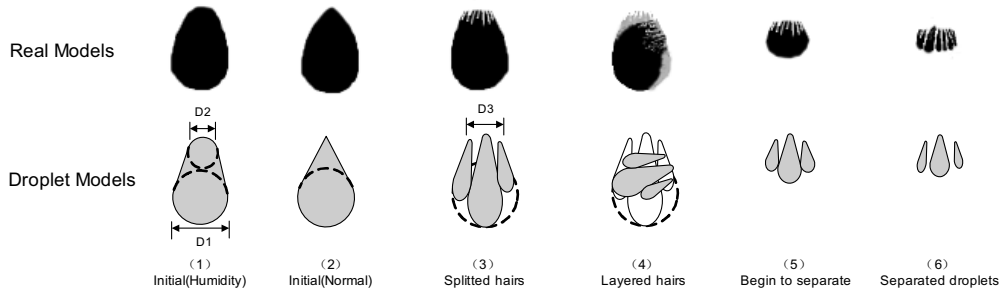


Figure 2. Variations of the droplet models to simulate real tangent area between brush and paper

without losing the power of expressing the “dry brush” effect which is rather difficult for the previous brush models. When applied to retrieving calligraphic character outlines, the brush parameters are determined according to the calligraphy image and a regeneration of the calligraphy with our model is just the retrieved result.

## 2. Parameterized Brush Model

The brush model proposed in this paper is a parameterized one. First, we define a set of interactive actions to simulate actual calligraphy/painting actions, and then we define a series of brush parameters, and discuss how these actions affect the variation of the parameters and how the parameters determine the final stroke model.

### 2.1. Basic Actions

There are four kinds of basic interactions defined in our model. *Dipping brush* is the initial action and this action will reset the parameters into initial values; *Lift and press the brush* is the action of modifying the pressure the brush imposes to the paper; *brush movement* scratches the brush on the paper and produces strokes; *Rotate brush-holder*, the fourth action type, is often performed by the calligraphers when they want to change the direction of the hair brush tip.

### 2.2. Normalized brush parameters

Basic actions decide the modification of properties of the brush. The most important parameters are listed as follows:

1. Fundamental brush parameters. This set includes brush length  $L$ , diameter  $D$  and hair number.
2. Brush velocity  $V$ . This parameter denotes the speed of brush movement and it is detected by the system in user interaction.
3. Humidity of the brush,  $H$ .
4. Thickness of pigment  $T$ . This parameter denotes the proportion of the amount of ink or Chinese traditional painting pigment to the amount of water.
5. Brush *pressure* is decided by the lift and press brush

action.

### 6. Tip direction $V_{tip}$ .

Except those in the fundamental brush model parameter set, all the parameters of the brush model are normalized for the sake of simplicity, that is, their domains all lie in the interval  $(0, 1)$ .

## 2.3. Stroke Area Models

In our approach, we use the “droplet” model to simulate the tangent area between the brush and the paper because this kind of model resembles real model better than previous ones[3, 4, 7]. There are different variations of the “droplet” model besides the standard droplet shown in figure 2-1. All the droplet models apply the same rules in computing the result and the rules of transformation among droplets under the driven of actions are derived from actual brush wielding experience.

The “droplet” model is a kind of 2D model. As just mentioned, the standard droplet is the region enclosed by two circles, with diameter  $D_1$  and  $D_2$  respectively, and the two common tangent lines of them. Both the standard droplet model and the variation 2 all contain a single droplet, whereas the remainder may consists of more than one.

The standard model and the variation 2 are two droplets used as the initial model when the brush is dropped. In fact, variation 2 is a special form of the standard model with  $D_2$  equals 0. The value of  $D_2$  is decided by the brush humidity and the fundamental brush parameters, including brush length and diameter.

The variation 4 of the droplet models is called a layered droplet. When wielding brush, the friction of the

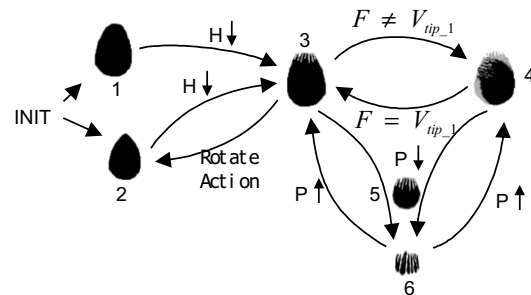


Figure 3. Action-driven model transformation

paper against the bottom part of the brush hairs may be inconsistent with the tip direction of the upper part of brush hairs, thus the layered droplet model is adopted.

Except for the fundamental brush parameters, all other parameters are determined according to the brush actions and thus the transformations between variations of the model are driven. The “state machine” is achieved from experience. The possible transformations between droplet model variations are shown in figure 3.

## 2.4. Computation of Stroke Area

Following previous researches, the entire stroke area is assumed as the trail the droplets have swept. The computation of the droplet model can be divided into two steps: evaluating the droplets in its local coordination system and then transforming it to paper coordination system. Given the location of the brush and the tip orientation, it is simple to get the transformation  $T$  and the sequent work is straightforward. So in this section we focus on the evaluation of the droplet in its local coordination system. Because most of the brush parameters are normalized, we do not intent to and can not calculate the physical model of the brush precisely.

The evaluation of the standard droplet model is quite simple.  $D_1 = D \cdot \text{pressure}$ , and it means that the size of the tangent stroke area varies according to the variation of the pressure the calligrapher imposes on the paper. The range of  $D_1$  is  $(0, D)$ .  $D_2 = D_1 \cdot kH$ ,  $k$  lies in the interval  $(0, 1)$  and is specified by the user at the initial time. A relative bigger  $k$  means that the “virtual calligrapher” tilts his brush holder to the side of the brush tip.  $h = L \cdot \text{pressure}$ . See figure 4-a.

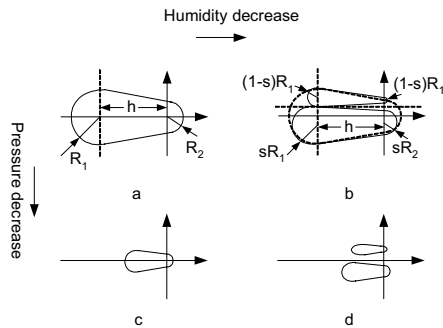


Figure 4. Evaluation of droplets

The figure 4-b shows how the variation model 1 or variation model 2 transforms to variation 3 or 4. Here, we introduce a random number  $s$ . The circle with radius  $R$  on either end of the droplet is divided into two circles with radius  $(1-s)R$  and  $sR$  respectively.

Figure c and d in figure 4 shows the droplets when pressure decrease. We can see from the figure that, when the brush is lifted, the droplet variation 3 or 4 transforms to the variation 6 ultimately.

Note that in figure 4, all  $R$ s are half the value of the

corresponding  $D$ s mentioned;  $R$  stands for radius and  $D$  for diameter.

The reunion and merging of the droplets are inverses of droplet separating and splitting.

When the parameters of the brush model are modified, the droplets model must be reevaluated. However, the brush moves continuously in real calligraphy, but this is impossible in computer. In our model, we simply evaluate droplets periodically and use the hull of the two sequentially evaluated droplet models to approximate the stroke during this time.

Before further discussion, we first define some terms. We call that each of the droplet retrieved in the same evaluation are *sibling droplets* with one another. When evaluating droplets model, each droplet can be derived by one of the three cases: inheritor from previous droplet, merged one from several droplets or otherwise one of the resulting droplets from a split. In any case, the previous droplet(s) is(are) the *parent(s)* of the result droplet and the latter is called a *descendant* of the former. After sorting the droplets in a droplet model by the  $y$  coordinate value in the droplet model’s local coordination system, some droplets are called *neighboring* ones if there are no other droplets between them in the sorted sequence.

The evaluation of the hull is not so straightforward because there may be case that the two droplet models are topologically inconsistent. On occurrence of such inconsistency may be during the time when droplet model 1 or 2 transforms to model 3. To avoid extreme complexity, we hold two assumptions:

*Assumption 1: Only neighboring sibling droplets can be merged into one new droplet and that the droplets’ order of one evaluation keeps the same as the order of the droplets’ parents in the previous evaluation.*

For example, suppose  $drop_{k-1}$ ,  $drop_k$  and  $drop_{k+1}$  are three neighboring droplets, in the next evaluation of the droplet model, the droplet(s) transformed from  $drop_k$  is bound to lies between the droplets transformed from  $drop_{k-1}$  and  $drop_{k+1}$ .

*Assumption 2: In two sequentially evaluated droplets, a single droplet can not both split into several and in the same time part of them merge with other droplets.*

Now we give the *hull rule*: each of the descendants or the parents of a droplet participates to the evaluation of the hull with this droplet.

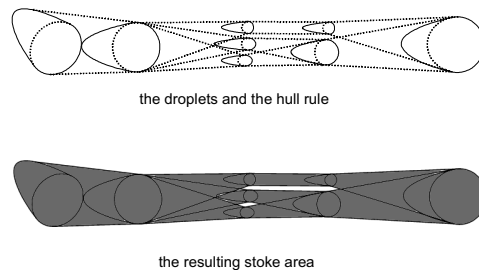


Figure 5. Hull rule. The hull of separated droplets elegantly expresses the “dry brush” effect.

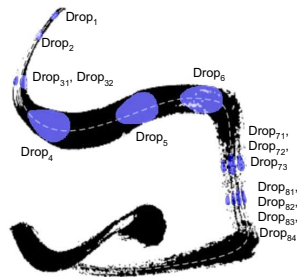
Figure 5 shows an example of applying the hull rule to evaluate the stroke area of a “dash” stroke, including the case of topologically difference.

### 3. Calligraphy Reconstruction and Modeling

Reconstruction of calligraphic characters and the modeling-purpose outline calculation can be divided into two steps: retrieving the brush parameters from the input calligraphy image and then regenerating the calligraphy using the virtual brush with the calculated parameter set.

#### 3.1. Brush Parameters Determination

From figure 3, we can see that humidity of the droplet virtual brush will drive droplet from variation 1 or 2 to variation 3, so, we must determine the value of  $H$  along the stroke. Naturally, we use the value of dark-pixel number divided by the source image by number of pixels the corresponding droplet covers as the measurement of stroke humidity. The stroke path is specified by user interactively (as the dashed line in the left side of figure 6).



	Total	Dark	Ratio
D <sub>1</sub>	164	107	65.3%
D <sub>2</sub>	197	66	33.5%
D <sub>31</sub>	117	21	17.9%
D <sub>32</sub>	225	44	19.6%
D <sub>4</sub>	3126	3126	100%
D <sub>5</sub>	3381	3381	100%
D <sub>6</sub>	3056	2577	84.3%
D <sub>71</sub>	218	82	37.6%
D <sub>72</sub>	479	201	42.0%
D <sub>73</sub>	407	169	41.5%
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Figure 6. Pixel sampling from source image to detect droplet ink deposit amount

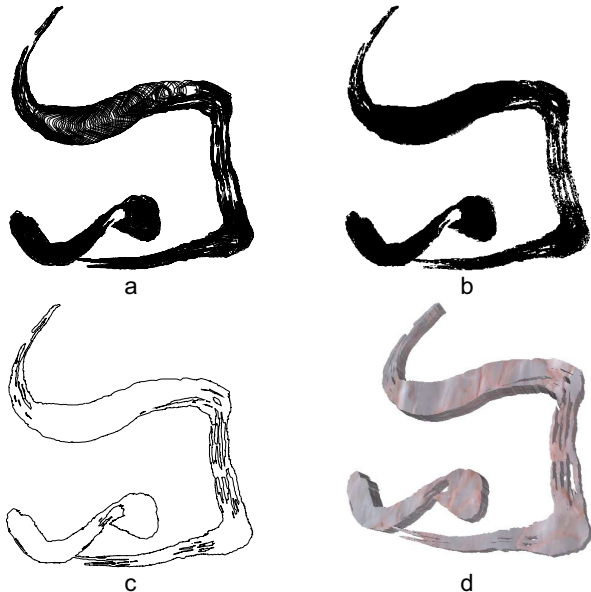


Figure 7. calligraphy reconstruction and modeling of the one shown in figure 6.

Figure 6 also shows the dark-pixel ratio of some calculated droplets. We can see from the data listed on the right table that when the dark ratio of a droplet drops, it may be divided into several smaller ones.

Given a stroke image, the algorithm of the droplet computing can be as follows:

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Input:
I:      Calligraphy image source
S:      Stroke path
v1,v2:  two valve humidity value, 1≥v2>v1≥0

Initialization:
Pi = P0; // the start point of S
D = stroke_width (Pi); V = stroke_tangent (Pi);
calculate_droplets(D, Pi, V) → {Dropij};
Add calculated droplets to final droplet set

Iteration:
for each calculated Dropij, do begin
    if dark_ratio(dropij) < v1
        decrease drop size of Dropij;
    else if dark_ratio(dropij) > v2
        set Dropij mergable;
    else
        split Dropij;
end
Merge mergable droplets;
Increase size of remaining mergable droplets;
Pi = march_on(S, Pi) // go to next segment of S;
D = stroke_width (Pi); V = stroke_tangent (Pi);
droplet_adjust(D, V, Dropij);
droplet_hull_with_the_parents_using_hull_rule
if(done) exit;
else go to Iteration.

```

The droplet valve humidity values,  $v1$  and  $v2$ , are determined interactively. If  $v1$  is close to 0 and  $v2$  close to 1, then no droplet splitting or merging will occur.

#### 3.2. Stroke Regeneration and Examples

After the droplets along the stroke path are retrieved, different use of the droplets can get different results. One application that can be done on the droplets is simply to hatch each of the droplets with proper calligraphy texture according to the ink-deposit amount of the given droplet.

Unlike the tangent area computed via traditional virtual brush model, the tangent area in our model has contained complete geometry information, which makes geometry operation on them possible. By union of the droplets retrieved, may also generated in “virtual calligraphy”, we can retrieve profiles of art characters in calligraphy or script style with extra outlines to indicate the stroke forks or dry brush effects.

Figure 7-a is the retrieved droplets and b is the result image after texturization of them. The figure in c is the union of the droplets. After the profiles are computed, the generation of 3D character model is straightforward. A simple extrude algorithm works quite well. Figure 7-d is the extruded solid model using the profile in c with marble texture, which can be used in virtual reality.

Figure 8-a shows two Chinese characters “方東” (means “orient”) generated by our painting system, b shows the computed droplets and the profile in c is the union of them. Since the calculated outlines are not smooth, we use a cubic uniform B-spline to approximate each loop of the generated stroke outlines. Figure d gives the result. We can see that the merged droplets in figure 8 express the stroke forks, a most important aspect of dry-brush effect correctly and elegantly.

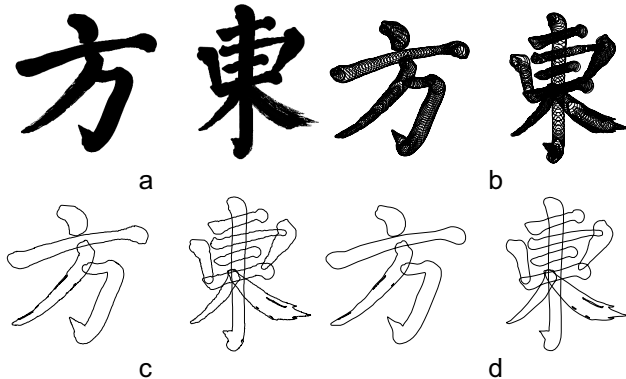


Figure 8. The calculation of the stroke outlines

As discussed in previous sections, our brush model is a parameterized one, so by adjusting the fundamental brush parameters we can get variations of a same font. Figure 9

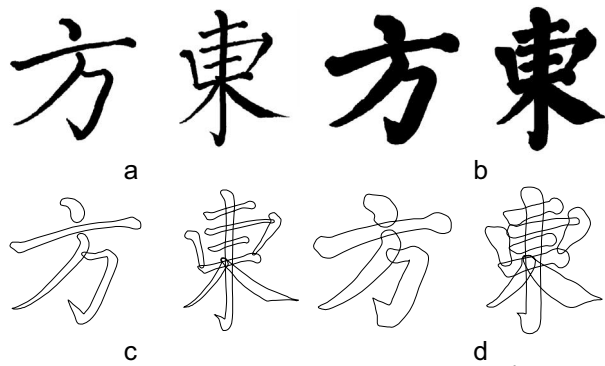


Figure 9. thin and bold version of “方東”

shows such an example.

The technique described has various applications. Because curves of the character profiles can be precisely retrieved, we can exports NC codes and significantly enhanced the ability of existing lettering machine, which currently can only deal with a predefined set of true type characters. This technique also introduces a new paradigm of 3D character modeling, and may be applied in various CAD systems.

Figure 10-b shows another example, which is a solid model of the calligraphy in a. “Dry brush” effect is widely used in this piece of work and outlines calculated from traditional “soft” brush cannot work well for such kind of calligraphy, however, our method is quite competent.

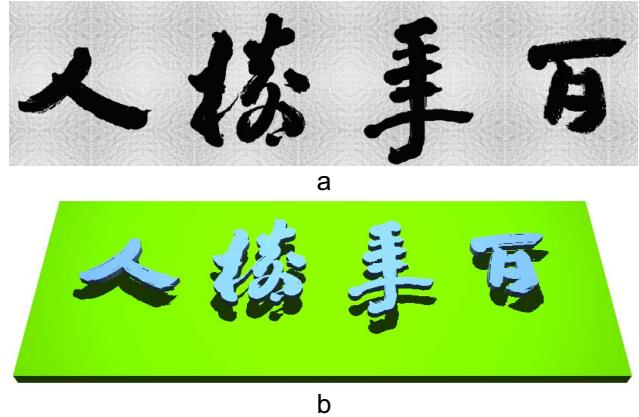


Figure 10. b is the extruded solid model of the calligraphy shown in a, a is the virtual calligraphy using the droplet brush model

#### 4. Reference

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