On the Effects of Haptic Display in Brush and Ink Simulation for Chinese Painting and Calligraphy

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Abstract

In this paper, we develop an interactive haptic system, which can be further aid for digital Chinese painting. When an artist is holding our force feedback device, one feels like holding a real painting brush with all the contact and bending forces, since the viscosity, friction, and the bending force of a brush touching the paper are simulated. First we derive a physical dynamics model as bending springs for bristles to construct a 3D brush, then we simulate the ink-water transfer system for ink spreading and color blending. Our system is a real-time system and users can interact with it holding a digital brush supported by either a Phantom force feedback device or a "WACOM pressure sensing pen" on a tablet. A pilot experiment was conducted, and the results show that brush writing with haptic feedback is better than that of same usual display but without haptic feedback.

Keywords

Haptics, Human Computer Interaction, Painting Systems, Chinese Painting, Calligraphy, Applications

1. Introduction

Chinese painting (water-and-ink) has a long history and its unique place in the world's fine arts is universally appreciated. The Chinese painting follows its own way of development, which is distinct from European painting arts. From Huang's commentary [SY81], "Chinese calligraphy and painting are traceable to the same origin, for ancient Chinese words were hieroglyphs consisting of pictures and figures of objects. Moreover, since Chinese calligraphy and Chinese ink-paint depend on the same materials – the brush, absorbing paper and ink made from soft coal soot mixed with gum, it may be said that Chinese calligraphy and painting are twins.”

Figure 1: System configuration. A PHANTOM force feedback device is provided for users to draw the Chinese painting or calligraphy with haptic perception.

1.1 Related Works

There are researches related to simulation of oriental painting, including Chinese painting, Japanese painting, etc. Strassmann developed Hairly Brushes [STR86] to simulate the traditional Japanese art known as *sumi-e*. Samples of position and pressure are interpolated as control points to form the stroke shape where pressure determines stroke width. Shi et al. [SOA88] developed an input device for calligraphic characters, where a tablet and a pressure sensing pen to measure how much force is applied to the pen when a user writes calligraphic characters. A modification of brush touch pattern (*footprint*) was also proposed in order to simulate the proper shape of a stroke. Ip and Wong [IW97, WI00] use 2D-based rotated-elliptic footprint and ink depositing parameters to paint calligraphic characters. Way and Shih [WS01] propose a method of synthesizing rock textures in Chinese landscape painting. They design two types of texture strokes, hemp-fiber and axe-cut, and the strokes are also 2D-based.

The methods be used in the above researches can be generally classified as flat-brush-based approach, which uses 2D brushes of various shapes, sizes and patterns to form the desired stroke. On the other hand, there are also researches related to 3D brush model. Jintae Lee [LEE99] developed a bristles model for oriental black-ink painting. He uses a deformation model of bending bristles with one end fixed in a brush shaft keeping perpendicular to paper. And it is used to present the shape of brush bundle. Bill Baxter, et al. [BSL01] developed an interactive painting system with the simulation of haptic feeling of brushes and a color transfer model. Stretch springs are used as brush skeletons to deform subdivision surface. This surface mesh of brush shows the geometric representation for the brush head. For the characteristics of Chinese brushes, some features in Chinese painting and calligraphy, like brush forking, are difficult to simulated by those two 3D methods. So we propose another brush bristle model, which is similar to Baxter's algorithm [BSL01]. But we did not use stretch springs. The bending springs are derived instead. We also design a special distribution of bristles for real-time Chinese brush simulation.

For the haptic feeling in painting, there are few research related to it. [SOA88] designed a pressure sensing pen. Following Newton's 3^{rd} Law, the force applied to hand is equal to the force applied from hand to pen. Baxter [BSL01] uses SensAble™ Phantom device as the input and haptic output device. The force is related to the penetration depth, pen tilt angle, and brush velocity. Our haptic simulation is modified from Baxter's, and we add a sensing distance s to hint users when the pen is approaching the paper.

Because strokes and materials are very different in Chinese painting and Western painting, we develop a painting system designed for the simulation of brushes. Bending springs are used to be our skeletons of a brush in order to simulate the dynamics. Therefore, we also can produce the effects of brush forking, based on the fading and spreading of ink and water.

1.2 Organization

The next section describes the overview of our system. Section 3 discusses the haptic issues. Section 4 describes our 3D brush model and bristles dynamics. Section 5 describes the detail of our ink-water simulation. Section 6 discusses the pigments and color mixing. Section 7 shows the result of our system. The last section is our conclusion and future work.

2. System Configuration

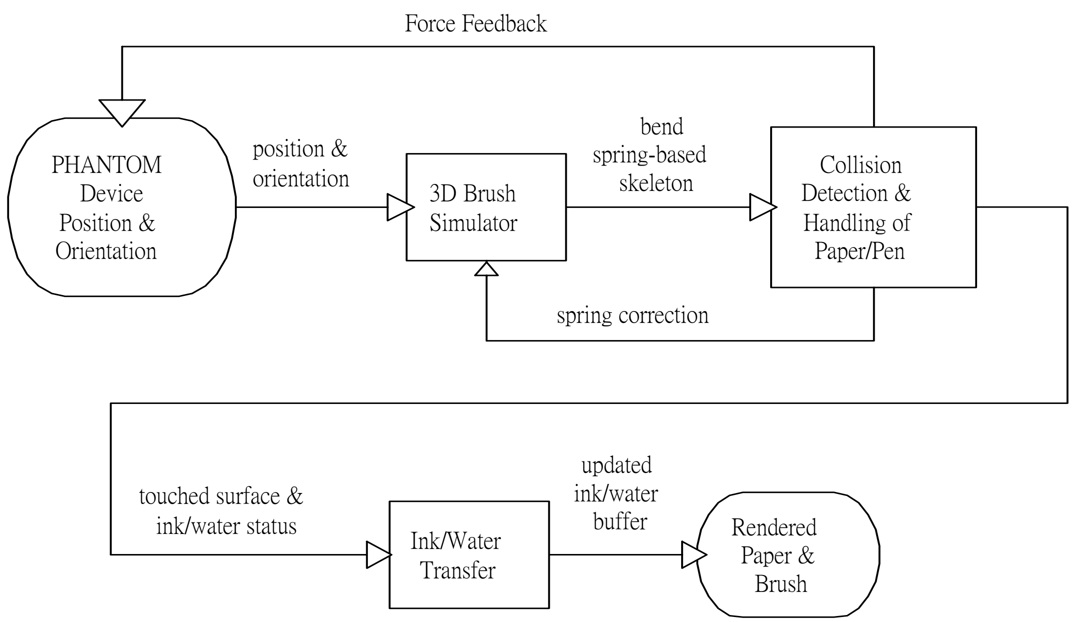

Figure 2: Flow Chart of our system

The proposed painting system consists of three parts: a force feedback device with 6 degrees of freedom (DOF), a 3D physical-based brush model and a paper model, and a model for ink and water transfer. User uses the 6 DOF force feedback device as an input device to simulate the painting process. With the force feedback, a user experiences the interaction between the pen and paper and he can feel more realistically. The painting system obtains the position, orientation, and force information from the 6 DOF force feedback device to complete the simulation. The brush model is constructed by using physical-based springs as the skeleton of the brush. The springs used in this system are not stretch springs as in most related researches; instead, the proposed system utilizes springs which adopt bending angle as the control variable. In the real world, bristles will not change their length when they are pressed. Therefore, bristles are more like bending springs rather than stretch springs. By using the information retrieved from the 6 DOF device, the brush model changes its position and orientation and simulates the shape it represents. Then, the detection of collision between the brush and paper is performed. When brush touches the paper, the shape of the brush would be adjusted because of the collision. Furthermore, the shape, orientation and position of brush and volume of ink and water contained in brush decide the stroke drawing on paper. In the meantime, force information is sent back to the force feedback device to simulate the feeling that user touches a paper. Lastly, the ink-water transfer model is responsible for the transfer of ink and water in brush and paper, and computes the final color represented to user.

3. Haptic Simulation

The haptic perception is very important for artists. In our previous work we implemented a system using 3D space tracker without haptic feedback ability. When users used that system, they complained that they could not touch the surface. If there is only a 3D tracker to track the position and orientation of the hand without haptic feedback, we could not touch the virtual object and apply force to it. It is very difficult to keep the hand in the exact position we want. It is also impossible to control the brush and to draw with the exact stroke size. Using only position values from tracker could not draw the subtle detail. The fun of painting would be lost without real-time interaction and force feedback.

We also made an experiment with stereo display before. Users put on stereo glasses to see the 3D object rendered by OpenGL in CRT monitor. They are attracted by the effect of 3D object appearing before the CRT monitor. But their eyes only get the rough depth perception of 3D objects. The exact depth information cannot be acquired with only stereo effect. Especially when the virtual brush is approaching the surface of paper, we can't control our hand in z direction correctly. As a consequence, the painting results were not what we want. In the field of Chinese painting, the control of stroke is very important. So it is critical to implement the system with force feedback.

There are some goals to achieve for haptic issues in our system here. First, our hands should have haptic perception if the brush held on hand approaches the virtual paper. Second, it should be natural to control the stroke size freely with different pressure from our hand.

3.1 Touch Simulation

When the brush approaches the virtual paper, we would like to provide haptic hints to the hand. Let s be the sensing distance to hint the user that the brush will touch the virtual paper. The length of bristles is l, and θ is the tilt angle of brush from the normal of paper surface. The distance from the root of bristles to the paper is d. Now the touch force in the direction of paper surface can be defined as:

$Ft = 0$ if $d > l*\cos\theta+s$, (force is zero from sensing distance),

$Ft = ks*(s+l*\cos\theta-d)$ if $l*\cos\theta < d \leqq l*\cos\theta+s$, (sensing force in sensing distance),

$Ft = ks*s + kb*(1-d/(l*\cos\theta))$ if $0 < d \leqq l*\cos\theta$, (bristle bending force when touching paper),

$Ft = ks*s + kb*1 + ke*(-d)$ if $d \leqq 0$ (brush shaft touching paper),

where ks, kb and ke are the stiffness of the sensing spring, bristles and brush shaft. It will be a real brush without sensing distance if s is equal to zero.

There are some other generic issues when implementing haptics. First is the hardware force limit. The force limit of our haptic hardware device is 1 newton. If the force applied on it is larger than that limit, an error exception will be generated in device driver level.

One thing is very important for the force feedback device. The force output function should be carefully designed. If the output function is not a continuous function, there will be some vibrations or buzzes from the motor of haptic device. Those will distract the user's attention when one crafts his painting.

Another important issue is about the haptic update rates. It is better to update the force in about 1k Hz or more. So the force function should be calculated as simple as possible. The Philosophy of haptics programming is, force feedback modeule should be small and fast, and graphics rendering and processing will take more time, they should be split.

3.2 Friction Simulation

Friction is related to two variables. One is the touch force *Ft*, and the other is coefficient of friction *kf,* where *kf* is related to the surface property between brush and paper. Since our brush may have different ink and water in different time, we slightly modified the simulated friction *Ff* as follows,

$Ff = 0$ if $Vxy = 0$, and

$Ff = kf * Ft * Vxy$ if $Vxy > 0$,

where *Vxy* is the velocity of our brush on paper surface. We calculate *kf*

$kf = k1 * (wetness + inkiness + k2)$,

where *k1* and *k2* are coefficient and *k1***k2* is equal to the coefficients of friction when the brush is dry and has no ink. This modified friction function will follow the continuity constraint for force output.

4. 3D Brush Modeling

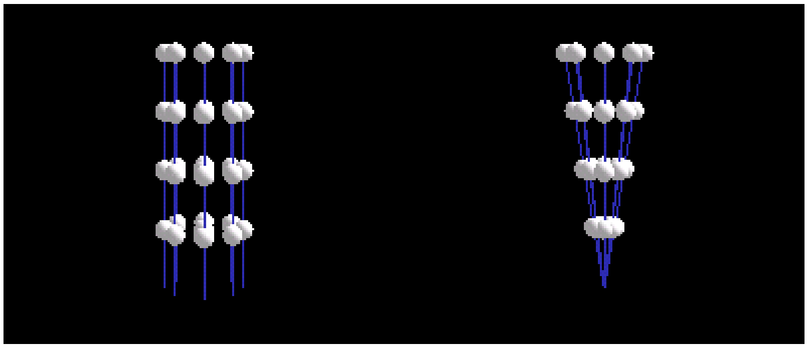

Figure 3: The 3D bristles models, model A and model B, where the hair should be vertically but in actual use, the water condensing force keeps all hair in a cone shape.

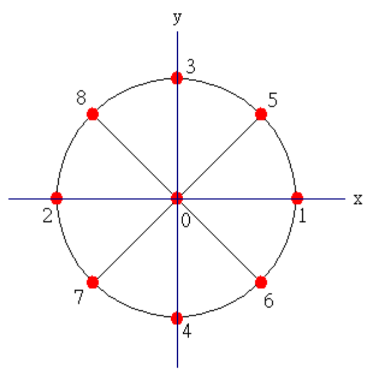

Figure 4: Nine bristles we put in 3D brushes.

A Chinese brush is composed of many bristles, and each bristle is like a bending spring. As Figure 2 above, a number of bristles N are distributed in the range of radius R around the center of the brush base O. The height of the brush is L, and the i^{th} bristle has a length l_i from the root r_i to the tip t_i.

Since there are so many bristles in the brush, it is hard to simulate all the bristles as springs in the real-time. However, using only one skeleton to simulate the whole brush is too crude to realistically represent the change of a brush, such as fork. To satisfying the need of speed and reality simultaneously, we use nine skeletons to simulate the brush and each skeleton represent a "*wisp*" or a bundle of hair. One skeleton is in the center and eight ones surround the center.

4.1 Newtonian Dynamics

According to the Newtonian dynamics, the physical relations between position, velocity, and force are formula below:

$$\begin{pmatrix} \dot{x} \\ \dot{v} \end{pmatrix} = \begin{pmatrix} v \\ F/M \end{pmatrix}.$$

When solving the value with the computer, there are two types of integration: explicit integration and implicit integration. Explicit integration uses force on this moment to compute the velocity next time segment, which makes it easier to be implemented. However, the error in this method will be larger as the time slot grows up, and the error will accumulate. Since the system needs to be stable, we use implicit integration. Implicit integration solves velocity and position next moment using the approximate value of force next moment.

Explicit integration:

$$V_{t+1} = V_t + F_t \times \frac{dt}{M},$$

$$X_{t+1} = X_t + V_{t+1} \times dt.$$

Implicit integration:

$$V_{t+1} = V_t + F_{t+1} \times \frac{dt}{M}, \qquad (1)$$

$$X_{t+1} = X_t + V_{t+1} \times dt. \qquad (2)$$

The first order Taylor expansion is applied to approximate force next moment as

$$F_{t+1} = F_t + \frac{\partial F}{\partial X} \times (X_{t+1} - X_t)\,. \qquad (3)$$

After substituting equation (3) into equation (1), and assuming $H = \frac{\partial F}{\partial x}$,

we get

$$V_{t+1} = V_t + \{F_t + H(X_{t+1} - X_t)\} \times \frac{dt}{M}\,. \,(4)$$

From equation (2) and (4), we get

$$V_{t+1} = V_t + \{F_t + H \times V_{t+1} \times dt\} \times \frac{dt}{M}$$

$$\Rightarrow V_{t+1} \times (I - H \times \frac{dt^2}{M}) = V_t + F_t \times \frac{dt}{M}$$

$$\Rightarrow V_{t+1} = (I - H \times \frac{dt^2}{M})^{-1} \times V_t + (I - H \times \frac{dt^2}{M})^{-1} \times F_t \times \frac{dt}{M} \Rightarrow \Delta V_{t+1} = V_{t+1} - V_t = (I - H \times \frac{dt^2}{M})^{-1} \times (F_t + H \times V_t \times dt) \times \frac{dt}{M}.$$

Finally the equation can be deduced as the form

$$\begin{pmatrix} \Delta X_{t+1} \\ \Delta V_{t+1} \end{pmatrix} = \begin{pmatrix} (\Delta V_{t+1} + V_t) \times dt \\ (I - H \times \frac{dt^2}{M})^{-1} \times (F_t + H \times V_t \times dt) \times \frac{dt}{M} \end{pmatrix}.$$

4.2 Aristotelian Dynamics

Newtonian dynamics is suitable for an ideal spring; however, the bristles are more like heavily damped springs. Therefore, Aristotelian dynamics is used instead, because this system does not deal with inertia.

$$\dot{x} = F/M\,,$$

$$\Delta X_{t+1} = (I - H \times \frac{dt}{M})^{-1} \times F_t \times \frac{dt}{M}\,.$$

4.3 Simulation of a Bending Spring

Since the spring model we use is bending spring, the relationship between force and displacement is replaced to that between force and angle. So we replace the displacement X and the velocity v in the formulas above with angle θ and angle velocity ω. Similarly, we can obtain the formulas for bending springs.

5. Ink-Water Transfer Simulation

When the brush touches the paper, if the quantity of ink and water storing on the paper surface layer is more than that on the brush surface layer, ink and water will infiltrate from the brush surface layer to the paper surface layer through the touch surface. In the real world, ink and water will also transfer back to the brush when it transfers from brush to paper. The total quantity of transferring is the difference between these two directions. We assume that the transfer rate R is proportional to V, the volume of ink and/or water on the surface layer. Then the transfer rate from brush to paper $Rb = Vb/k$, and the transfer rate from paper to brush is $Rp = Vp/k$.

Then the volume transferring from the brush to the paper is $Vtrans = Rb - Rp = (Vb - Vp) / k$. Therefore, the formula of transfer becomes

$Vp' = Vp + Vtrans = Vb/k + Vp \times (k-1)/k,$ and

$Vb' = Vb - Vtrans = Vb \times (k-1)/k + Vp/k.$

However, for the artists' convenience, the behaviors that ink and water transfer back to the brush are not necessary. Since the ink transferred back will make the stroke dirty. So, the transfer formula is revised as

$$Vp' = Vb/k + Vp \times (k-1)/k \qquad \text{if } Vb > Vp,$$

$$Vp' = Vp \qquad \text{if } Vb \leqq Vp.$$

$$Vb' = Vb \times (k-1)/k + Vp/k \qquad \text{if } Vb > Vp,$$

$$Vb' = Vb \qquad \text{if } Vb \leqq Vp.$$

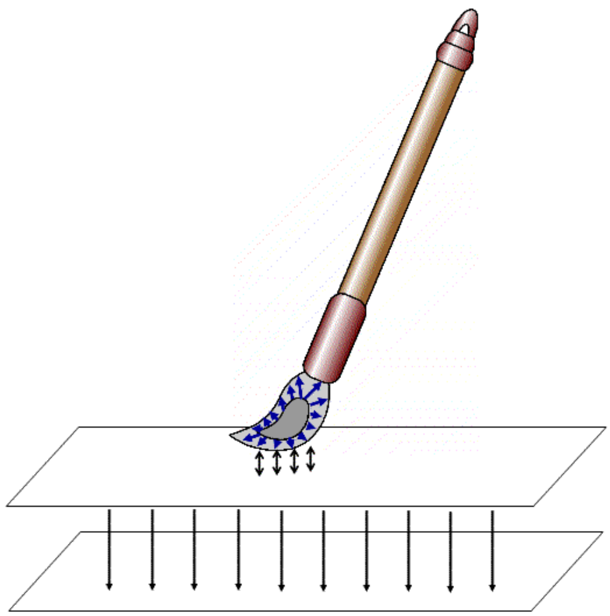

Figure 5: Multi-layered structure of brush and paper.

5.1 Multi-layered Structure of Brush and Paper

The proposed system adopts a multi-layered structure to simulate the transfer between ink and water. Both the brush and the paper have two layers, a surface layer and an interior layer. The surface layer of the brush represents the part which really touches the paper and can interact with the surface of the paper, while the interior layer of the brush is responsible for storing ink and water to supply the ink and water diminished during the painting procedure. The surface layer of the paper is the place where users really paint on. Ink and water is transferred to this layer to achieve the effect of painting. The interior layer of the paper is the place where the ink settles in, and will not be affected by the brush directly. The surface layers of the brush and paper, and the interior layer of brush, are wet; water information is stored in these layers. The interior layer of the paper is totally dry.

The transfer is performed in three situations. The first type of transfer is that ink and water transfers between the surface layers of brush and paper on the moment the brush touching the paper. The second type of transfer is that the ink and water stored in the interior layer of brush transfer to the surface layer of the brush to supply the lost ink and water, which happens when the ink and water on the surface layer reduce under a proportion of the interior layer as the time passes by. The last one is the transfer from the surface layer of paper to the interior layer, which will be activated when the paper is drying.

6. Experiment Design and Results

Our system had been used for more than six artists. Figure 7 and figure 8 are some painting results by our system. With our haptic simulation on force feedback device, users are very satisfied and enjoy the fun of painting.

In order to know whether the haptic feedback in writing is useful or not, we have designed an experiment to verify our hypothesis. The hypothesis is that (method A) brush writing with haptic feedback and visual display of brush is better than that of (method B) visual display of brush only.

As a pilot study, six subjects were used, all of them are undergraduate students of Dept. of CSIE, National Taiwan University. Method A and method B were randomized in sequence, and were given to subjects to write a Chinese character “forever(永)”. After the test, the subjects were asked to use a pencil to check which method is better in achieving this simple task, whether it is method A or B.

The results show that four out of six subjects select method A (with haptic feedback) over method B (without haptic feedback). In order to be significantly different, and to corroborate our initial hypothesis, another full scale experiment is under development, and the final report will be given later.

Figure 7: Calligraphy. The upper two are Chinese words, “water-ink”. The lower one is Chinese word, “spring”

7. Future Work

In this paper we developed an interactive painting system for Chinese painting and calligraphy. There are still some special properties in Chinese brush that we didn’t simulat. The dryness painting style is important when we are drawing stone and mountain.

For the user interface, we will develop more brush model for Chinese painting, because painter will need several brushes to craft an artwork. We only prepare 2 different brushes in our system now. The brushes with bristle from different fur should have different parameters.

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Figure 8: Some paintings by Babylon Tian, B.S S.R. Chen, and Maggie Luo