An Interactive Design System for Water Flow Stains on Outdoor Images

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Abstract. Weathering and aging effects are essential for synthesizing realistic outdoor images in the field of film production and scene production. The problem here is that photographed materials do not yield desired images without editing, and manual painting requires labor-intensive work as well as professional skills. In this paper, we focus on a salient aging effect, *stains by water flows*, and present a system that allows the user to add such stains directly and easily onto outdoor images. Our system represents a water droplet with a particle and simulates the dissolution, transport and sedimentation of deposits using particles in the regions specified by the user. In the simulation, realistic and complex stains can be obtained by accounting for the roughness of the surface where water flows. Furthermore, the user can adjust the amount of deposits according to the perspective in the image. The quick feedback of the simulation enables interactive manipulation. We demonstrate the effectiveness of our system through various results and user evaluations.

Key words: weathering and aging, image processing, particle system

1 Introduction

Photorealistic reproduction of weathering and aging phenomena often plays an important role in the field of film production and scene production. Especially, *weathering and aging of buildings*, e.g., rusts, stains and pollution caused by rainfalls, chemical reaction, ultraviolet light and other various factors, have high demand because buildings are ubiquitous in our daily lives and thus might look unnatural without such phenomena. A usual way to seek such realism is to use photographed materials as texture images and edit them to obtain desired results. However, looking for appropriate materials itself is not easy, and editing materials requires labor-intensive work as well as professional skills.

In this paper, we focus on a salient aging effect, *stains by water flows*, and present a system that allows the user to add such stains directly and easily onto building walls in outdoor images. Our system represents a water droplet with a particle and simulates the dissolution, transport and sedimentation of deposits using particles in the regions specified by the user. This simulation scheme is based on a simple model proposed for 3D models by Dorsey et al. [2], but we modify it to improve the performance and the usability for image editing. In the simulation, realistic and complex stains can be obtained by accounting for the surface roughness where water flows. The user can specify the initial and terminal positions of particles by drawing a few lines. Furthermore, the user can adjust the amount of deposits according to the perspective in the image; using a pair of auxiliary lines drawn by the user, our system makes water flow stains shorter and thinner as the distance from the viewpoint gets longer. The quick feedback of the simulation enables interactive manipulation. We demonstrate the effectiveness of our system through various results and user evaluations.

2 Related Work

Realistic representation of weathering and aging phenomena has been an important theme in the field of computer graphics. The previous methods can be broadly grouped into *image-based approaches* that obtain information from real photographs and *simulation-based methods* that handle specific targets such as rusts, cracks and dirt. Here we briefly introduce some of them, and refer to the survey paper by Merillou et al. [8] for more information.

Image-based Approaches. Gu et al. [6] obtained and modeled time-space varying bidirectional distribution functions (BRDFs), and then reproduced temporal variations of materials. Wang et al. [12] constructed a manifold that represents the temporal variation of a material using BRDFs measured at various points on the material in order to reproduce the transition of complicated texture patterns. While these methods target 3D models, Xue et al. [13] applied Wang et al.'s method to objects in 2D images to synthesize the weathered or de-weathered appearance. Although image-based approaches successfully reproduce various texture patterns, they suffer from handling physical properties of the target objects because they do not account for the physical law of the phenomena.

Simulation-based Approaches. Physically-based simulations of weathering and aging have been applied to various targets such as stones [4], paint peeling [9], cracks of clay-like materials [11] and wooden materials [14]. These methods are accompanied by geometric changes. Previous methods that do not handle geometric changes include weathering and aging by dust [7], rust [3] and moss [1].

Dorsey et al. [2] employed a particle simulation to reproduce stains caused by flows streaming on 3D models. In their method, particles dissolve and carry deposits, and the deposits are accumulated on the surface according to a set of partial differential equations. Their method can represent various patterns of realistic stains by tuning parameters, but lacks flexible control for designing stains. On the other hand, our simulation scheme is a modified version of Dorsey et al.'s method specialized for 2D image editing, and collaborates with the user interface for designing water flow stains.

Dorsey et al.'s Model. In Dorsey et al.'s model, a particle represents a water droplet parameterized by the mass m, position $\mathbf{x}$, velocity $\mathbf{v}$, and the amount of dissolved deposits S. Particles are initially assigned on the surface of a 3D model at random by a rainfall, and then flow downward under the influence of the gravity and frictions. Particles interact with each other due to the repulsive forces among them. Water is absorbed into the object surface, and thus the surface also has a set of parameters, namely, the surface roughness r, the amount of absorbed water w, the rate for absorption k_a, the saturated amount of absorption a, and the amount of sediment D. Regarding the deposits carried by water particles, there are attributes such as the adhesion rate constant k_S, the solubility rate constant k_D, the evaporation rate I_{sun}, and the initial deposition amount on the surface I_D. Dorsey et al.'s model uses a scalar surface roughness r or a displacement map on the surface in order to obtain the interesting movement of particles; the roughness makes particles disperse whereas the displacement map let particles move slowly across a bumpy surface, yielding more sediment along cracks and valleys. Consequently, the absorption of water is modeled as follows;

$$\frac{\partial m}{\partial t} = -k_a \frac{a-w}{a} \frac{A}{m}, \tag{1}$$

$$\frac{\partial w}{\partial t} = k_a \frac{a-w}{a} \frac{m}{A} - I_{sun}, \tag{2}$$

where t denotes the simulation time and A is the diameter of the water particle. Similarly, the solution and sedimentation of deposits are modeled as follows;

$$\frac{\partial S}{\partial t} = -k_S S + k_D D \frac{m}{A}, \tag{3}$$

$$\frac{\partial D}{\partial t} = k_S S \frac{A}{m} - k_D D + I_D. \tag{4}$$

When the mass m becomes smaller than a certain threshold, the particle is removed from the simulation.

3 User Interface

This section describes our prototype system for designing images containing water flow stains. Our system adds such stains using particle simulations, and allows the user to easily specify the regions where the water particles flow on the input image.

Fig. 1 shows the screenshot of our prototype system. In the left window that displays the input image and flowing particles (blue), the user can directly specify the regions for simulation and the perspective of the input image, and then obtain simulated results quickly. In the right window, the user can configure the parameters and other settings of the simulation. In the middle panel, the user can select the color of deposits using either of the color pallet, color chooser or color picker. The current color is displayed at the bottom.

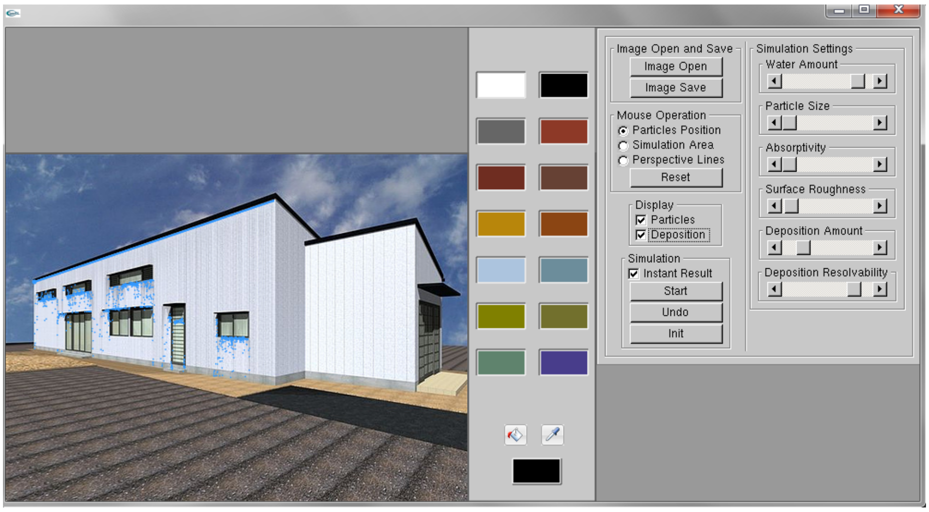


Fig. 1. Screenshot of our system.[1]

3.1 Control Lines

In the left window in Fig. 1, the user specifies three types of control lines (or curves) to control the particle simulation (Fig. 2);

Source line (the blue line in Fig. 2(a)): to specify the initial position of particles. Particles are emitted from these lines.

Terminal lines (the green lines in Fig. 2(a)): to specify the positions where the simulation terminates. Particles are removed when they touch these lines.

Perspective lines (the two red lines in Fig. 2(b)): to specify the perspective of the input image. The amount of deposits is adjusted according to the perspective of the input image, specified by these lines. See Section 4 for more details.

The user can draw a straight line by clicking its endpoints and a curve by dragging the cursor.

3.2 Simulation Parameters

The user can adjust the following six parameters to make a variety of water flow stains using scroll bars. The way each parameter influences the simulation is described in Section 4.

[1] Author of the input image: heavymoonj
URL: http://www.flickr.com/photos/heavymoonj/261996484/

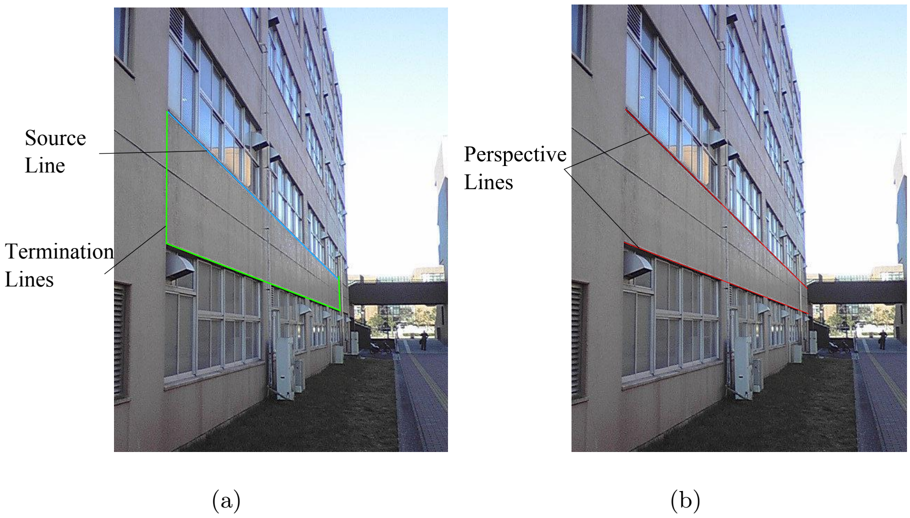


Fig. 2. Three types of control lines for the particle simulation. (a) The blue line specifies the source position of particles, and the green lines represent the terminal positions; particles are removed when they touch these lines. (b) The perspective of the input image is specified by the pair of the two red lines in order to adjust the amount of deposits according to the perspective.

Water Amount. The parameter for the water amount specifies the number of particles. By increasing this parameter, more complex stains caused by more flows can be obtained (Fig. 3).

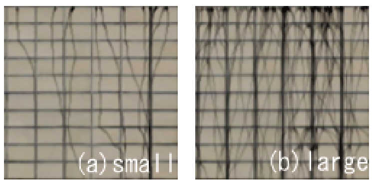


Fig. 3. Effect of Water Amount.

Particle Size. The relative size of particles with regard to the input image can be adjusted using this parameter (Fig. 4).

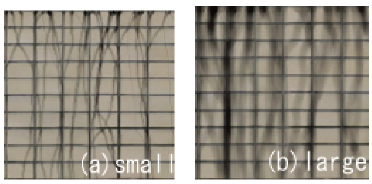


Fig. 4. Effect of Particle Size.

Absorptivity. This parameter specifies the rate with which the mass of each particle decreases. The flow distance of each particle becomes short by increasing this parameter (Fig. 5).

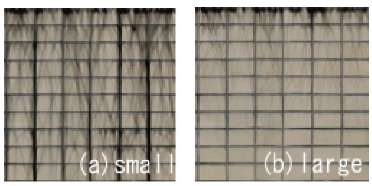


Fig. 5. Effect of Absorptivity.

Surface Roughness. This parameter determines how much each particle is diffused and decelerated due to the bumps on the surface. By increasing this parameter, more deposits tend to accumulate at cracks and ditches (Fig. 6).

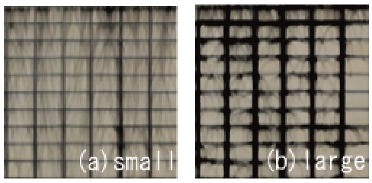


Fig. 6. Effect of Surface Roughness.

Deposition Amount. This parameter specifies the amount of deposits attached on the surface. A large value yields thick stains (Fig. 7).

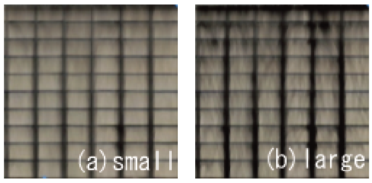


Fig. 7. Effect of Deposition Amount.

Deposition Resolvability. This parameter determines how easily deposits dissolve in water particles. A large value yields a blurred image (Fig. 8).

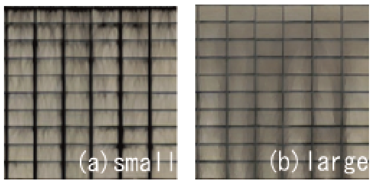


Fig. 8. Effect of Deposition Resolvability.

4 Simulation Scheme

This section describes the simulation scheme to control water particles. Our scheme is based on Dorsey et al.'s model [2] because of its simplicity. In their model, each particle represents a water droplet that dissolves and transports deposits which are then accumulated along the tracks of particles. While their model targets the 3D space, we simulates on the 2D domain, i.e., the input image. We simplify their model to reduce the number of parameters and to provide faster feedback to the user. Furthermore, we extend it to handle the surface roughness on which particles flow and to adjust the amount of deposits according to the perspective of the image.

Basic Modifications to Dorsey et al.'s Model. As described above, we modify Dorsey et al.'s model for interactive simulations on a 2D image. We define the xy coordinate system along the horizontal and vertical edges of the image. To accelerate the simulation, we ignore the interaction among particles and frictions but only consider the gravity. According to Eq. (1), (2), (3) and (4), the variations of the mass and amount of absorbed water depend on the diameter of particles, which means the "thickness" of the deposit color changes according to the diameter. This is not desirable for our purpose because we want to control the "thickness" only by I_d (i.e., *Deposition Amount* in Section 3.2), and thus we omit m/A and A/m from the equations. In Eq. (3) and (4), we set the range of k_D and k_S [0, 1], and let $k_S = 1 - k_D$ to reduce the number of parameters. The user can control k_a and k_D as *Absorptivity* and *Deposition Resolvability* respectively, as described in Section 3.2.

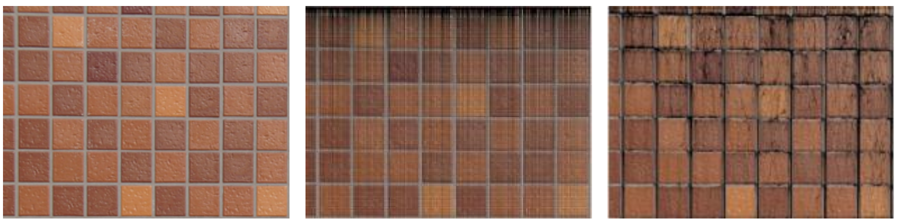
Displacement due to Luminance Variations. As shown in Fig. 9(a), the luminance values change greatly in general across cracks and valleys in images. Therefore, we construct the displacement map from the variations of the luminance values in the input image, and use the surface roughness r as a coefficient to amplify the influence of the map. The particle velocity $\mathbf{v} = (v_x, v_y)$ is reduced according to the variations of the luminance values;

$$v_x^{diffuse} = b\, r\, \xi\, M_y(\mathbf{x}), \tag{5}$$

$$\frac{\partial v_x}{\partial t} = v_x^{diffuse} - v_x \frac{M_x(\mathbf{x})}{r_{max} - r + 1}, \tag{6}$$

$$\frac{\partial v_y}{\partial t} = -v_y \frac{M_y(\mathbf{x})}{r_{max} - r + 1}, \tag{7}$$

where $M_x(\mathbf{x})$ and $M_y(\mathbf{x})$ are the horizontal and vertical variations of luminance values at particle position $\mathbf{x}$, b is a constant, $\xi \in [-1, 1]$ is a random value, and r_{max} is the maximum of r. The user can control r as *Surface Roughness* as described in Section 3.2. Fig. 9 shows the results (c) with and (b) without accounting for the surface roughness. Compared to Fig. 9(b), Fig. 9(c) exhibits more sedimentation along the ditches, which makes the result look much more realistic.



(a) (b) (c)

Fig. 9. Simulation results (c) with and (b) without accounting for the displacement defined by the variations of luminance values in (a) the input image.

Adjustment to the Perspective in the Image. In a perspective view, water flow stains look shorter and thinner as the distance from the viewpoint becomes greater. However, such sense of distance is lost on an image, and thus we fail to reproduce the perspective effect when directly applying our scheme (Fig. 10(b)). To address this issue, our system lets the user specify the perspective using a pair of auxiliary lines (i.e., *Perspective Lines* in Section 3.1). See Fig. 10(a) for an illustration. Let $d(p_x)$ be the vertical distance between the two lines at $x = p_x$ and d_{max} be the maximum of $d(p_x)$. To adjust the perspective in the input image, our system multiplies the gravity, the particle mass and the deposition amount by $\rho = d(x)/d_{max}$, where x is the x coordinate of the particle position. Fig. 10(c) illustrates that the adjustment successfully reproduces the perspective effect.

(a) (b) (c)

Fig. 10. (a) An illustration for the perspective adjustment. Simulated results (c) with and (b) without the perspective adjustment.

5 Results

We implemented our prototype system using C++ language, OpenGL and GLUI, and executed our system on a PC with a Xeon 2.66GHZ, 2GB RAM, and an NVIDIA Quadro FX 3450 graphics card. Fig. 11 shows the resultant images with water flow stains synthesized using our system. The user succeeded to design realistic stains within moderate time. Regarding the time for editing, the user generally spent the most of time in tuning parameters. As the image size becomes larger, the simulations takes longer as shown in Fig. 12 We believe that the time for simulations will be much shorter using minified images and GPU implementation in future work.

User Test. To validate the effectiveness of our system, we performed a user test to compare its performance to the *Adobe Photoshop*®. Six students, all novice users of our system and image editing software, participated in the study. After

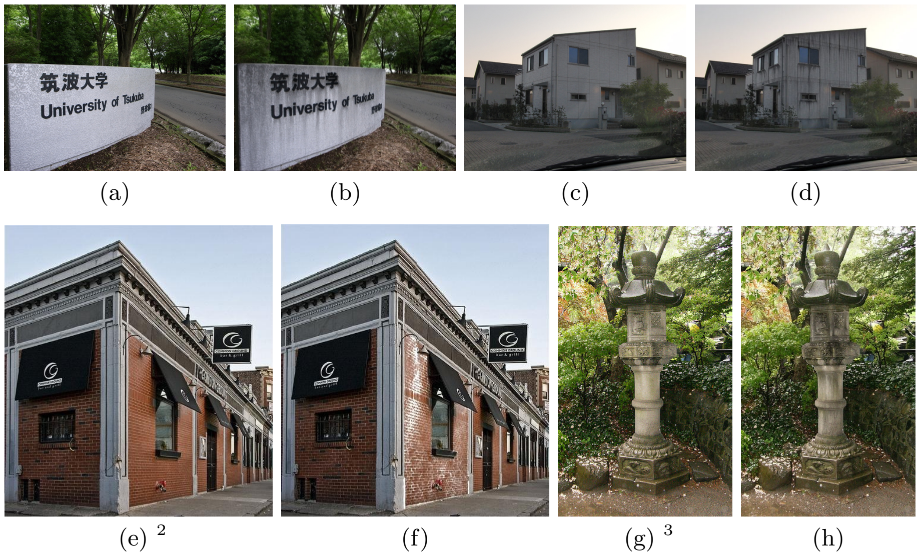
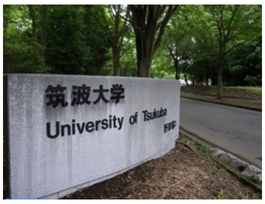


Fig. 11. (b)(d)(f)(h) Synthesized images with water flow stains using our system. The image sizes of their inputs are (a) 500×375, (c) 512×384, (e) 452×491, and (g) 300×500 pixels. The times for editing are about (b) 3 min, (d) 10 min, (f) 4 min, and (h) 5 min.

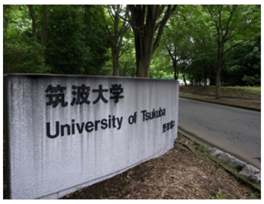
a brief tutorial, each subject was asked to synthesize water flow stains on the tile image (Fig. 14(b)) in reference to the stained tile image (a real photograph, Fig. 14(a)), using either our system or the alternative software (Photoshop). The testing order of the software was alternated between subjects; three used Photoshop first, and the other three used our prototype system first. The subjects were allowed to work on the task until satisfied, for up to 20 minutes. Fig. 10 shows some of the resulting images. Fig. 13(a) shows the time of design process across six subjects and two design tools. Subjects using our system overall took less than 70% of the time when they did using Photoshop. Fig. 13(b) shows the subjective evaluation of the produced images. Ten people voted on the resulting images, regarding how natural each image is. A binomial test of the scores shows that our system performed better than the Photoshop in making water flow stains except for the results of participant #6, who seemed to misunderstand our system and tried to use it as an ordinary paint tool. These results show that our system achieves better quality in less time than the Adobe Photoshop.

[2] Author of the input image: new hobby
URL: http://www.flickr.com/photos/newhobby/2427677211/

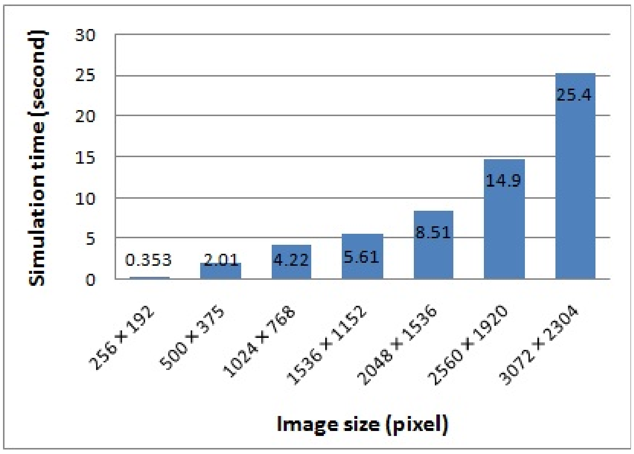
[3] Author of the input image: peterjr1961
URL: http://www.flickr.com/photos/peterjr1961/3506811726/



(a) 256 × 192

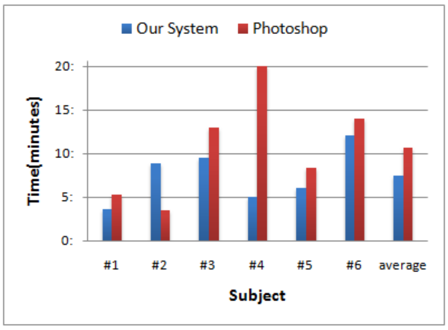


(b) 3072 × 2304

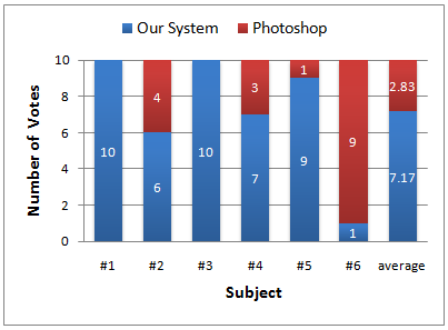


(c) Simulation time

Fig. 12. (a)(b) Resultant images with different image sizes for the same scene as Fig. 11(a). The image size is listed under each image. (c) shows the simulation time (second) for a single execution with each image size.

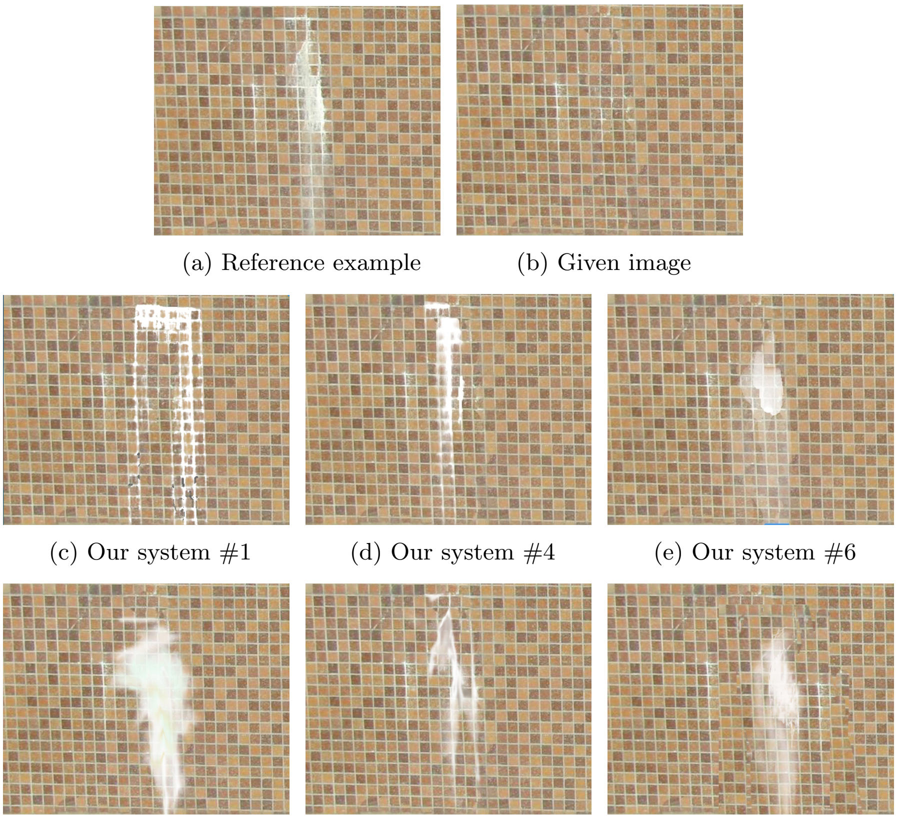


(a) Time for operations



(b) Votes on the qualities

Fig. 13. Graphs summarizing the results of a user test. Each of six subjects was asked to synthesize two images, one using our system and the other using Photoshop, so that the images became satisfying for the subject. (a) shows the time of design process across six subjects and two design tools. (b) Then ten people voted on the result, regarding how natural each image is. The number represents that of votes for each system.



(a) Reference example (b) Given image

(c) Our system #1 (d) Our system #4 (e) Our system #6

(f) Photoshop #1 (g) Photoshop #4 (h) Photoshop #6

Fig. 14. Results of the user test, comparing our system to Photoshop. The users were presented (a) a reference example (a real photograph) and asked to edit (b) a given image until the user gets satisfied. The middle row (c)(d)(e) presents the results by different users using our system whereas the bottom row (f)(g)(h) shows those using Photoshop.

6 Conclusion and Future work

We have proposed an interactive system that helps users design water flow stains on outdoor images. Based on a particle simulation modified from Dorsey et al.'s model, our system allows the user to specify the initial and terminal positions of particles by drawing a few control lines (Section 3.1). Additionally, the user can adjust the simulation to the perspective in the input image by drawing a pair of auxiliary lines (Section 3.1). Regarding the simulation scheme (Section 4), we reduced the parameters used in Dorsey et al.'s model to improve the usability, and ignored the interaction between particles to accelerate simulations. Our system automatically estimates the bumpiness of the surface where particle flows, using the luminance variations in the input image. A user test demonstrated that our system yields better results more quickly than a generic paint tool in the task of synthesizing water flow stains (Section 5). A limitation of our current system is that luminance artifacts (e.g., specular highlights, shadows) in the input image might affect the simulation, which will be avoided by removing such artifacts [5] or by manually editing the displacement map (Section 4). Because our current system fixes the direction of gravity vertically downward and assumes the surface on which particles flow is flat, the flow directions are limited. The use of the control mesh [10] will improve the controllability of particle flows.

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