Model-driven Virtual Mezzotint Techniques

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Abstract

Mezzotint is a traditional printing technique that is categorized into copperplate printing where an entire plate surface is roughened by some steel tools. In this paper the authors propose a method to realize two mezzotint techniques by replacing some physical models for the plate making process. The main characteristic of mezzotint is that roughening, scraping, and burnishing the plate will result on a gradation of color from black to white. The paraboloidal incising model and the sweeped paraboloidal model are applied to roughen the plate. Reducing and smoothing operations are introduced to scrape and burnish the plate. By some experiments the authors prove the proposed methods to synthesize copperplate print images.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

Copperplate printing [Has94, Lea84] is one of the traditional *intaglio* printing techniques to express and republish technical images or fine arts. In general, the copperplate printing consists of four processes: 1) plate making, 2) ink applying, 3) wiping, and 4) pressing. According to the difference of the plate making method, there are many kinds of techniques such as drypoint, engraving, mezzotint, and etching. This paper focuses on mezzotint in which an entire plate surface is roughened by various steel tools. A rocker and a halftone comb, usually used for mezzotint, create many dots and lines while burrs arise out of the plate, respectively. After the roughening process, the plate is scraped using a *scraper* in order to control the remaining ink around burrs. The scraped portions of the plate produce halftones at the print. If the artist wants brighter effects, the plate is burnished using a *burnisher*. The difference of the incised shape affects impressions of the work. In mezzotint, an important characteristic is the gradation from velvety black to high-lighted white that a print acquires depending on how the plate is roughened, scraped, and burnished. It is a very onerous and patient process for artists to roughen an entire plate. For example, to roughen a 50×65cm sized plate it takes about $30 \sim 40$ days. Sometimes it is very hard and not safe for beginners to deal with such tools or acid chemicals. Therefore, the subject of this study is to simulate the making procedure of copperplate printing safely and easily even for non-expert users and children using Computer Graphics (CG) technology.

As one of CG research fields, non-photorealistic rendering (NPR) has been studied passionately, and has also been applied to simulate fine arts. Tasaki *et al*. have already proposed a rendering method of virtual drypoint [TMO04] with a physics-based rendering (PBR). Since their method simulates the making procedure and the physical phenomena that occurs in the actual process of drypoint, the appearance of the rendering image is expected to be similar to the real drypoint print with physical fidelity.

In this paper we propose two methods for virtual mezzotint by a PBR approach. Both methods are based on the one by Tasaki [TMO04], thus it can realize mezzotint techniques replacing only the plate making model. The paraboloidal incising model used in virtual drypoint is applied to roughen the plate, and reducing and smoothing operations are also introduced in order to scrape and burnish the plate. A mezzotint print looks like halftoning [VB99] or dithering. Ostromoukhov *et al*. described a dithering method [OH99] and they indicate that their results look like mezzotint in its appearance. Sourin proposed a functionally based representation [Sou01]. In contrast, our method uses a hight-field in order to express the plate shape. It is a convenient and straightforward expression to simulate ink behavior on the plate.

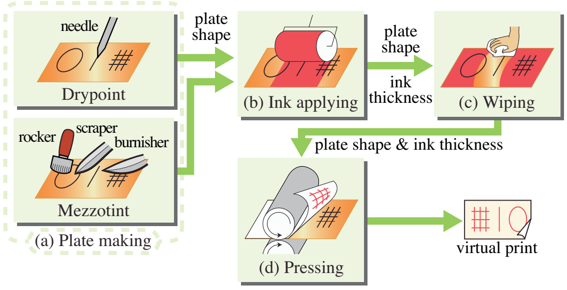
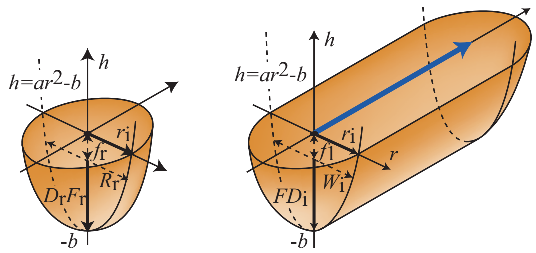


Figure 1: *Overview of virtual copperplate printing*



(a) Dot shape for a rocker (b) Line shape for a halftone comb

Figure 2: *Shape functions of stroke for roughening tools*

2. Physical Model for Virtual Mezzotint

In this section, the model of the plate making process of virtual mezzotint (Figure 1) is described for two techniques. Ideal physical models for them are as follows.

1. Paraboloidal shape function for a dot (using a rocker).
2. Sweeped paraboloidal shape function for a line (using a halftone comb).
3. Scraping burrs by reducing plate heights.
4. Burnishing plate surface by smoothing plate heights.
5. Hand fluctuation of tools by fractal.

Mezzotint consists of three sub-processes. First, roughening by a rocker is performed. Either one or both processes, scraping and burnishing can be performed after roughening.

2.1. Physical model for roughening

Here two kinds of roughening models are introduced.

A dot model for a rocker: A rocker looks like a comb that has many small teeth, and it can make many microscopic dots on a plate surface. The rocker is distinguished by N_{tr}: the number of teeth an inch (#65, #85 and #100 are generally used). This value is used for defining some other parameters. The incising shape for a dot by a tooth of a virtual rocker illustrated in Figure 2a is based on the paraboloidal model of drypoint [TMO04] and is expressed as:

$$h = ar^2 - b \quad (0 \le r \le r_{\mathrm{i}}), \tag{1}$$

$$a = \frac{D}{R^2}, \quad b = DF + f, \quad r_{\mathrm{i}} = \sqrt{\frac{b}{a}},$$

where, D and R indicate the depth and radius of incised dot, respectively. f represents the fluctuation of force by a hand, and follows a normal distribution $\mathrm{N}(0, \sigma^2{}_{\mathrm{r}})$. Although F represents the rocker pressure, it is not considered yet. The burr formed around the dot is also expressed with the model of drypoint. The domain of burr $(r_{\mathrm{i}} < r \le r_{\mathrm{b}})$ is calculated with the law of volume conservation which assumes that the whole of incised volume becomes a burr. Approximately, under a 2-D crosssectional area the equation (2) is applied, and r_{b} is determined from the equation.

$$\int_0^{r_{\mathrm{b}}} \left(ar^2 - b\right) dr = 0, \tag{2}$$

$$r_{\mathrm{b}} = \sqrt{\frac{3b}{a}} = \sqrt{3}r_{\mathrm{i}}. \tag{3}$$

An actual rocker makes many dots in a line at one operation. This one-dimensional operation is repeated in longitudinal, latitudinal, and diagonal directions. One time roughening consists of a set of these operations. As the roughening result, dots fill the entire plate evenly. In the roughening model, this operation is approximated by two-dimensional random dots. The number of dots that should be made in a unit area N_{unit} is calculated with N_{tr} as:

$$N_{\mathrm{unit}} = \left\{ \frac{N_{\mathrm{tr}}}{25.4 \times 10^3} \right\}^2 \ [\mathrm{dot}/\mu\mathrm{m}^2]. \tag{4}$$

This roughening process can be repeated several times according to the real roughening process.

A line model for a halftone comb: A halftone comb also has some teeth with the number N_{th}. However, it produces not dots but lines which run along a ruler. Artists deal with it to produce a cross-hatching on the entire plate surface. The incising function of a line using a virtual halftone comb is illustrated in Figure 2b. It is represented with a paraboloidal model sweeped along with an incising line. The basic shape of the line is also expressed by the equation 1. The halftone comb produces some lines by one operation as shown in Figure 3. The number of lines n is calculated as:

$$n = W_{\mathrm{h}} \frac{N_{\mathrm{th}} \sin\theta}{25.4 \times 10^3}, \tag{5}$$

where, W_{h} and θ are the width of the halftone comb and the angle according to the x-axis, respectively, where, some fluctuations occur in actual incising. The force fractal affects the depth and the width of the incised line. The interval and parallelism of each operation affect the location and gradient of the incised line. The tilt of the halftone comb affects the force balance. The depth fluctuation f is given by the one-dimensional midpoint displacement method with standard deviation σ_{hd}, and the interval of each operation is given by normal distribution $\mathrm{N}(0, \sigma_{\mathrm{hi}})$.

2.2. Physical model for scraping by a scraper

The concept of scraping operation consists in using the scraper to cut away the burrs. It is expressed by reducing

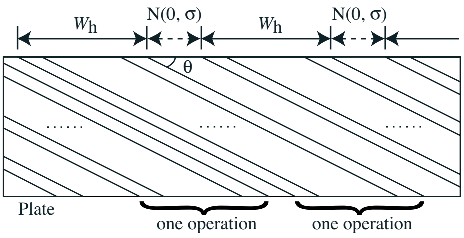


Figure 3: *Incising lines with a halftone comb*

Table 1: *The values of the parameters used in the models*

Parameter	Value
Depth of incised dot with rocker D_r	12.0μm
Radius of incised dot with rocker R_r	60.0μm
Number of rocker teeth N_{tr}	100†
SD of depth fluctuation with rocker σ_r	2.0μm
Depth of incised line with halftone comb D_h	15.0μm
Width of incised line with halftone comb W_h	5000μm†
Radius of incised line with halftone comb R_h	60.0μm
Number of halftone comb teeth N_{th}	65†
SD of depth fluctuation with halftone comb σ_{hd}	2.0μm
SD of interval fluctuation with halftone comb σ_{hi}	100μm
Reduction rate of scraping α	0.85
Smoothing rate of burnishing β	0.2

These values are decided empirically except ones indicated by '†'.

the plate height $p(\mathbf{X})$ with the reduction rate α:

$$p'(\mathbf{X}) = \min\left(p(\mathbf{X}),\ \alpha \max_{\mathbf{X}\in\mathbf{R}} p(\mathbf{X})\right). \tag{6}$$

The region to scrape; $\mathbf{R} = \left\{R(\mathbf{X}) \mid \mathbf{X} = (i,j) \in \mathcal{N}^2\right\}$ is given with a label image holding the number of scraping operations from 0 to 16. The number is expressed by color tones as illustrated in Figure 4a.

2.3. Physical model for burnishing by a burnisher

However the concept of burnishing operation is similar to the one of scraping, the burnisher refills the dents with the burrs instead of cutting them away. It is expressed by smoothing the plate height with the smoothing rate β:

$$p'(\mathbf{X}) = p(\mathbf{X}) - \beta\left(p(\mathbf{X}) - \frac{1}{N}\sum_{\mathbf{X}\in\mathbf{R}} p(\mathbf{X})\right), \tag{7}$$

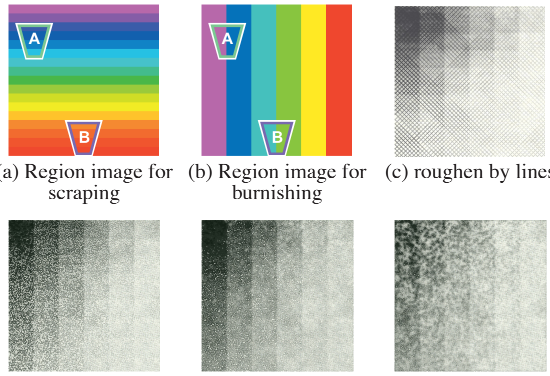
where, N is the number of plate cells in $\mathbf{R}$ which is the region to burnish given with a label image holding the number of burnishing operations from 0 to 5. The number is expressed by color tones as illustrated in Figure 4b.

3. Experiments and Discussion

The methods proposed in 2 have been implemented. Table 1 shows the values of the parameters used in the experiments.

(a) Scraping levels [times] (b) Burnishing levels [times]

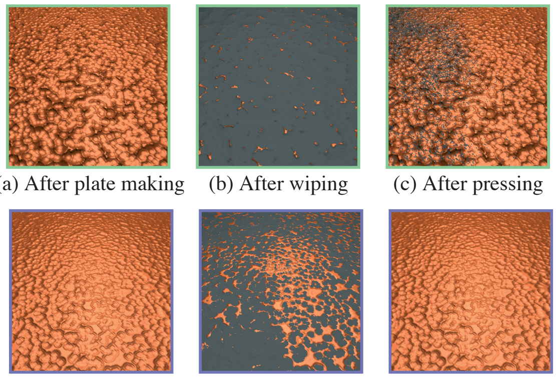
Figure 4: *Color bars for scraping and burnishing levels*



(a) Region image for scraping (b) Region image for burnishing (c) roughen by lines

(d) 5 times roughen (e) 12 times roughen (f) 20 times roughen

Figure 5: *Region images and virtual mezzotint (2×2cm)*



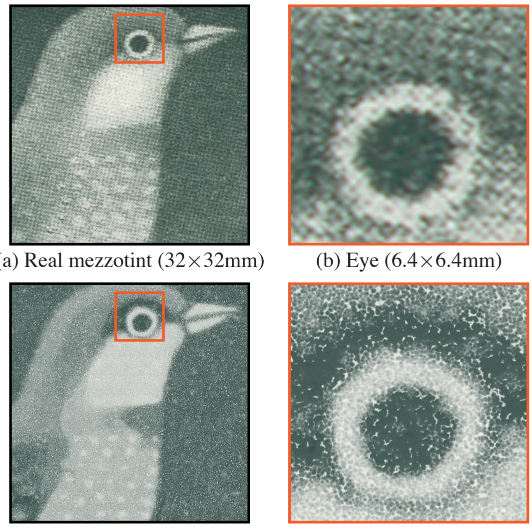
(a) After plate making (b) After wiping (c) After pressing

(d) After plate making (e) After wiping (f) After pressing

Figure 6: *The state of the virtual plate surface (Upper row: area A, lower row: area B, indicated in Figure 5a and 5b.)*

A plate shape consists of a resolution of 2,540dpi to represent the shape of incised lines finely. *e.g.* a 5×5cm sized image is composed of 5,000×5,000pixels.

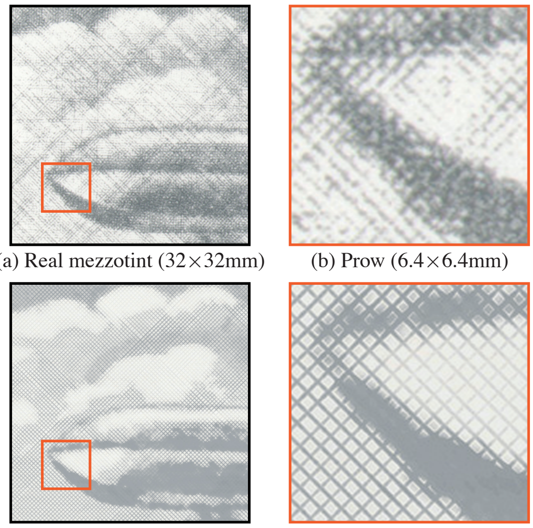
Figure 5 shows the results of a phantom study to specify the differences by roughening times, scraping, and burnishing. Figure 5c is synthesized with a virtual halftone comb. Figures 5d, 5e, and 5f are synthesized with a virtual rocker. They are based on the phantom region images 5a for scraping and 5b for burnishing. In these prints, a gradation effect can be observed as an important property of mezzotint. The difference among 5d, 5e, and 5f is the roughened times. Too few roughening such as 5d neglects some portions of plate surface to be flat. Too much roughening such as 5f breaks the burrs and collapses gradation. To demonstrate the effect of the model, the standard deviation of the fractal σ_C deciding the irregularities of the wipe cloth surface described in



(a) Real mezzotint (32×32mm) (b) Eye (6.4×6.4mm)

(c) Virtual mezzotint (32×32mm) (d) Eye (6.4×6.4mm)

Figure 7: *Comparison of real (upper row, [Has94]) and virtual (lower row) prints of mezzotint by a rocker*



(a) Real mezzotint (32×32mm) (b) Prow (6.4×6.4mm)

(c) Virtual mezzotint (32×32mm) (d) Prow (6.4×6.4mm)

Figure 8: *Comparison of real (upper row, [Has94]) and virtual (lower row) prints of mezzotint by a halftone comb*

[TMO04] is reduced to 1.0μm from 3.0μm. Figure 6 shows the virtual plate and virtual ink in the case of Figure 5e by OpenGL. The portions as specified by color rectangles in 5a and 5b are corresponding to each row in Figure 6.

For a practical experiment of mezzotint the authors pick out works by K. Hasegawa [Has94]. Figure 7 and 8 indicate comparisons of real and virtual mezzotint prints by a rocker and a halftone comb, respectively, and the experiments have done with 3.2×3.2cm portions. The sizes of the real works are 26.4×35.4cm and 16.8×30.5cm, respectively. In these experiments contrast and brightness control was performed to virtual prints based on the histograms of real and virtual prints. The region images for scraping and burnishing are generated manually based on the real prints with an image processing software. The virtual print by the rocker shown in Figure 7c has a good impression. However, the magnified image shown in Figure 7d has unnatural white portions and has no texture of paper. On the other hand, the virtual print by the halftone comb shown in Figure 8c and 8d has very artificial impression. This is because that ink adhesion with deformed paper under high pressure of a press machine is not considerated accurately in the present printing model.

4. Conclusion

Physics based rendering methods for two kinds of mezzotint were proposed. The paraboloidal incising model and sweeped paraboloidal model were applied to roughen a plate using a rocker and halftone comb, respectively. A height reducing model was proposed to scrape the burrs with a scraper. A height smoothing model was proposed to burnish the plate surface. These models realized the gradation that is a feature of mezzotint. The authors proved the basic effects of proposed model by some experiments.

For future study, the structure of paper, and expression of the plate surface to represent more detailed shapes should be discussed. A rendering method of scratches on metals [BPMG04] by Bosch *et al*. is also useful for our system to render the shape of plate surface more accurate. The proposed methods utilize two types region images as the input data. Automated input data generation by pattern recognition is expected to study.

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