Measurement and Reproduction of Reflective/Transmissive Lights in Ink Brush Painting on Absorbent Paper

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1. Introduction

From the viewpoint of archaeology, it is necessary to preserve historical artifacts for posterity. Digital archiving is one of the most effective ways to sustain these ancient objects into the future. In this paper, we focus on archiving handwritten documents with ink brush painting on an absorbent paper. Appearances of the documents can be vary among observing environments as shown in Fig.1. Such difference tells us something about the brushstroke of handwriting, for example. According to a related work [3], it is required to obtain both reflectance and transmittance for relatively thin objects to reproduce the appearance realistically.

As for existing digital archives of handwritten documents, there are "Toji hyakugomonzyo" which is a national treasure in Kyoto Prefectural Library and Archives [1] and Lotus Sutra which is an "important cultural property" of Japan in Nara National Museum [2]. Although digital images of them are available on the Web, we cannot make realistic replica of them even if we print the image on a paper.

For making realistic replica, it is necessary to consider an optical properties of an ink absorption into the paper. Therefore, we propose a method of measurement that obtains not only reflectance [4] but also transmittance, and duplicates a replica being the same texture representation of the documents by using a consumer printer.

(a) Under light (b) Against light

Fig. 1: Appearance of the handwritten document.

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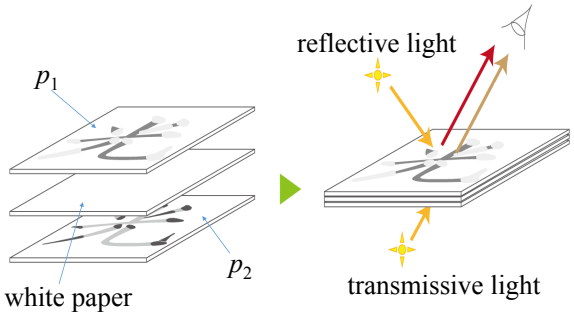


Fig. 2: Pair of printed papers for replica. To enhance dynamic range, an additional white paper is inserted.

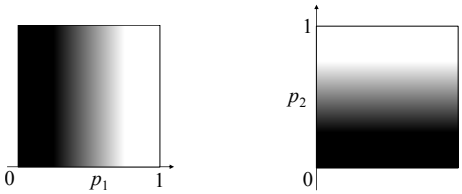
2. Measurement and Reproduction

In order to duplicate realistic replica, it is necessary to reproduce the original reflectance and transmittance simultaneously. Therefore, we propose a novel approach which prints a pair of paper with different printing patterns and combined these papers into one, as shown in Fig.2. Thus, our replica has a layer structure.

To determine the printing pattern, it is necessary to aquire a relationship between optical properties and ink intensities of upper layer p_1 and lower layer p_2. Kubelka-Munk theory is a conventional model-based approach, however it requires accurate material parameters of printing paper and ink to determine p_1 and p_2, precisely.

Therefore, we employ a sample-based approach which measures the relationship. As shown in Fig.3, we prepare a pair of paper that is printed white-to-black gradation along horizontal and vertical directions, respectively. We combine these two into one to measure reflectance and transmittance of all combinations of p_1 and p_2 by using layered two different gradation patterns. We measured the optical properties of it in a darkroom, as shown in Fig.4.

According to the measurement, we can obtain a look-up table which describes correspondences between optical properties (R, T) and ink intensities (p_1, p_2). Referring the look-up table reversely, it is possible to determine p_1 and p_2 from reflectance and transmittance. We also measure the reflectance R and transmittance T for every pixel on the



(a) Upper layer (b) Lower layer

Fig. 3: Gradation patterns to make a look-up table.

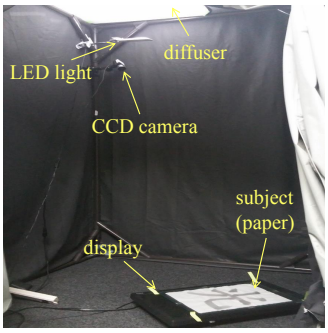


Fig. 4: Set up for measuring optical properties.

(a) Under light (b) Against light

Fig. 5: Appearance of the replica.

character written on the document to be replicated. To find the optimal p_1 and p_2 from the look-up table, we define error function as

$$\underset{p_1,p_2}{\operatorname{argmin}}(|R - r(p_1,p_2)| + |T - t(p_1,p_2)|). \quad (1)$$

By minimizing the error function, p_1 and p_2 can be obtained. Finally, we print two sheets of paper according to p_1 and p_2 obtained for every pixel, and combine them. As a result, we create a replica which mimics the optical property of the subject as shown in Fig.5.

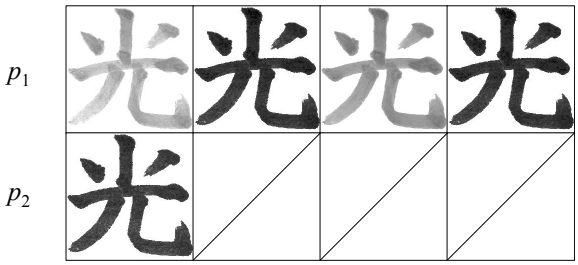
3. Experimental Results

We evaluate the effectiveness of controlling ink intensities on upper and lower layers, compared with controlling only ink intensities on upper layer. In this paper, we determine the ink intensities of upper layer p_1 and lower layer p_2 according to Eq.(1). We call this replica as two-RT and additionally create three different replicas of controlling only ink intensities on upper layer. The p_1 value of these three different replicas are decided by three different equations as:

$$\underset{p_1}{\operatorname{argmin}}(|R - r(p_1,1)| + |T - t(p_1,1)|), \quad (2)$$

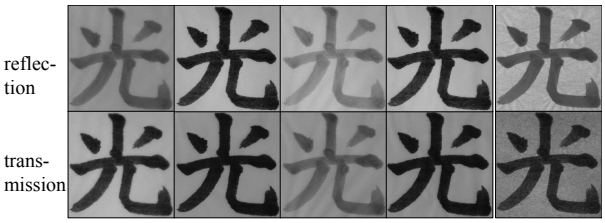
$$\underset{p_1}{\operatorname{argmin}}\,|R - r(p_1,1)|, \quad (3)$$

$$\underset{p_1}{\operatorname{argmin}}\,|T - t(p_1,1)|. \quad (4)$$



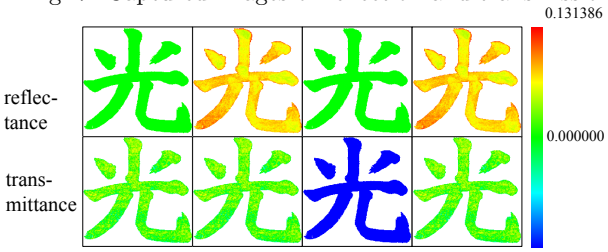
(a) two-RT (our method) (b) one-RT (c) one-R (d) one-T

Fig. 6: Decided values obtained by the look-up table.



(a) two-RT (our method) (b) one-RT (c) one-R (d) one-T (e) subject

Fig. 7: Captured images of reflection and transmission.



(a) two-RT (our method) (b) one-RT (c) one-R (d) one-T

Fig. 8: Error distributions.

Note that, we did not print anything on lower layer, that corresponds to p_2=1 in these cases. We call replicas produced by (2), (3), (4) as one-RT, one-R, and one-T, respectively. Figure 6 shows the values of p_1 and p_2, determined by each ways. Using these values, we created four types of replica shown in Fig.7 (a)-(d). The original appearance is shown on Fig.7 (e). According to Fig.8, our method (a) reproduces both reflectance and transmittance more accurately than the other methods (b), (c) and (d). It shows difficulty to reproduce both optical properties at the same time by controlling only upper layer pattern. Thus, our method which controls ink intensities on both upper and lower layer is appropriate to reproduce reflectance and transmittance simultaneously. Our future task is reproducing texture of paper of documents.

References

[1] http://hyakugo.kyoto.jp/en/
[2] http://www.narahaku.go.jp/english/collection/d-753-0-1.html
[3] Atsushi Ishida, Sosuke Kaji, Lisa Park, Kensuke Tobitani, Aya Shiraiwa, Eriko Aiba, and Noriko Nagata, "Lace Curtain: Rendering and Animating Woven Cloth Based on an Impression-Evaluation Model," Proceedings of ACM SIGGRAPH 2013, Anaheim, Jul.21-25,
[4] W. Matusik, B. Ajdin, J. Gu, J. Lawrence, H. P. A. Lensch, F. Pellacini, and S. Rusinkiewicz, ACM Trans. Graphics, 28(5), 128:1 (2009).