Digital Imaging Systems for Historical Documents

Improvement of Legibility by Frequency Filters

Kimiyoshi Miyata and Hiroshi Kurushima***
** Department of Museum Science, ** Department of History*
National Museum of Japanese History
Sakura-shi, Chiba Pref., Japan

Abstract

As the first step in historical research it is very important to read historical documents. Historians like to peruse original documents directly, but as in practice this may be difficult conventional photographic systems are often used. Historical documents vary greatly in type and size, therefore the application of digital imaging systems promises to contribute to the development of historical research.

In this article, we at first point out the basic requirements of a digital imaging system used for historical research. Then according to these requirements, we introduce an image processing technique to improve the legibility of historical documents by spatial frequency filters. Since the paper used in some historical documents is very thin, letters written on the reverse side of the paper can be observed from the front side. As a result, letters on both sides of the paper become mixed up when the documents are read. This is one reason for the legibility of the documents to be degraded. We separate these two kinds of letters having different frequency components by two kinds of spatial frequency filters, which are fundamentally analogous to the un-sharp mask filter technique. These filters have different responsibilities in the frequency component to determine whether the letters are on the front side or not. The experimental results showed that the letters on the front side were separated well, but further considerations and additional experiments are necessary to improve the legibility of the historical documents.

Introduction

In historical research based on historical documents, the first step is to read the documents carefully and deeply. Many kinds of valuable documents are stored in private houses. Because in most cases the researchers cannot take these documents away, conventional photographic imaging systems such as micro-film, photo prints, and film readers are widely used so that the documents can be read in the researchers' laboratories. Recent digital imaging systems promise to benefit historical research with instant image checking, low cost and some support of digital image processing techniques.

Since the paper used in some historical documents is very thin, letters written on the reverse side of the paper can be observed from the front. As a result, letters on both sides of the paper become mixed up when the documents are read. This is one reason for the legibility of the documents to be degraded.

In this study, spatial frequency filters are designed to extract the letters written on the front side of a document from images taken by a digital camera. In the design of the filters, we suppose that the letters written on both sides originally have the same sharp edges, which have a high frequency component, but the letters on the reverse side are blurred by a low-pass filter effect of the paper. We separate these two kinds of letters having different frequency components by using two kinds of spatial frequency filters, which are fundamentally analogous to the un-sharp mask filter technique. These filters have different responsibilities in the frequency component to determine whether the letters are on the front side or not. The details are described in the following sections.

Basic Requirements for Historical Research

Listed below are the basic requirements of a digital imaging system for historical research carried out as an investigation by historians.

(1) Ease of Use

Usually historians have not had special training for taking images. Their investigations may be limited to a short period of time, and therefore ease of use is very important.

(2) Reasonable Image Quality

Because high quality images can be taken by a photographer after the investigation, a reasonable image quality is suitable at the investigation stage. The quality required in the investigation is sufficient for the documents to be read. Excessively high image quality is not required.

(3) Instant Image Checking

Many documents are fragile, making it difficult to take repeated images. It is therefore best to be able to check an image immediately after it is shot.

(4) Low Cost

The number of historical documents used in investigations is huge, therefore the cost of taking images is a severe problem.

(5) Flexible and Simple Set-Up of Imaging System

Generally, there is no photographic studio at investigation sites, therefore imaging conditions such as lighting conditions are very poor. Furthermore, historical documents vary greatly in size and type, and usually there is not enough space to take an image. A flexible and simple set-up is also important in the digital imaging system.

(6) Support System

The following support systems are helpful for historians: digital image processing techniques including enlargement or placement of images in a side-by-side position; some techniques for easy accessibility including image data retrieval; image data sharing through network systems; and easy maintenance of the image data. Reliability for long-term storage is also required. The improvement of legibility described in this article is referred to as part of the support system.

Improvement of Legibility

Because the letters written in historical documents show slight gradation, with partial blurring or fadig, a conventional thresholding method applied to digital images has difficulty in determining whether the letters were written on the front or reverse side of the paper. A method based on the spatial frequency information of the letters is therefore proposed in this research.

In terms of spatial frequency, there are two kinds of blur level for the contours of the letters. The contours of letters written on the front side of the paper are sharp, whereas the contours of letters on the reverse side are relatively blurred. If shift invariance can be assumed and the surface of the paper is flat, the difference in blur level in the digital image tells us which letters are written on the front side. After the separation of the letters based on this idea, some kinds of post-image processing such as hi-pass filtering and mirror reverse for the reverse side letters can be applied to improve legibility. Figure 1 shows the experimental set-up, and Figure 2 is a flowchart of the experiment.

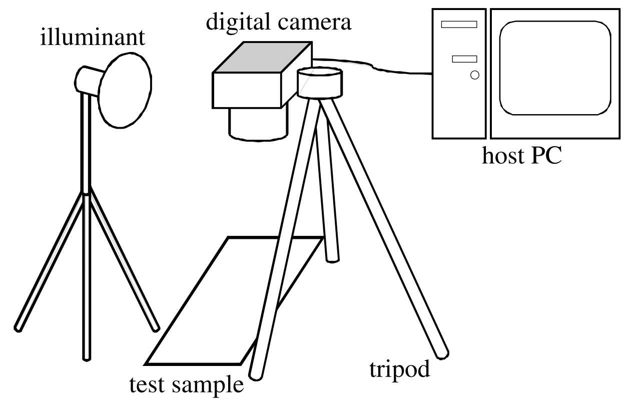


Figure 1. Experimental set-up.

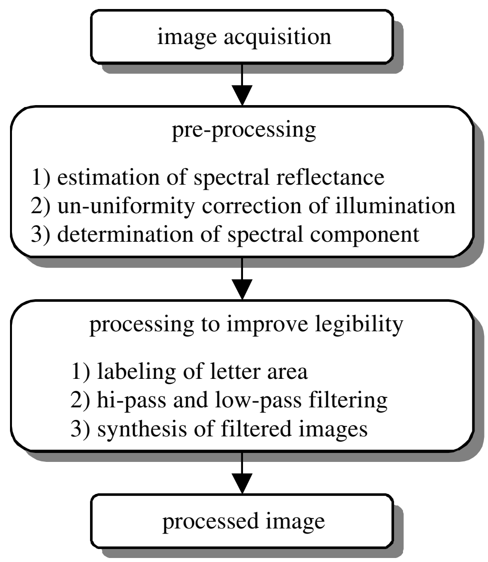


Figure 2. Flowchart of the experiment.

1) Image Acquisition

A digital camera, which is a single lens reflex type, is used in this experiment. This camera has a CCD sensor to yield 8 bit/pixel in the R, G and B color channels. A single illuminant is used to provide a simplified set-up according to the basic requirements mentioned in the previous section. Un-uniformity is a problem under single illuminant lighting conditions. This is therefore corrected by a method mentioned in a later section.

Figure 3 shows a test sample printed on both sides of the printing paper using an ink jet color printer. There are 4 Japanese syllabary characters on the front side, and 3 letters on the reverse side. All of the letters are printed using black ink only. The letters on the reverse side can be observed through the paper, and are mixed with the letters on the front side. This is a cause of degradation in legibility.

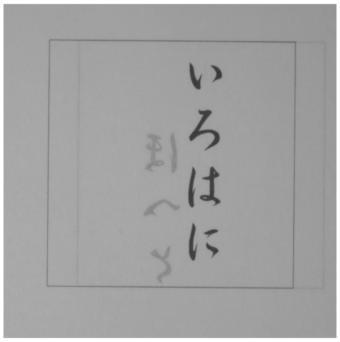


Figure 3. Test sample.

2) Pre-processing

2.1) Estimation of Spectral Reflectance

Many recent studies have addressed estimating the spectral reflectance of objects. Insofar as the basic requirements of this research are concerned, obtaining the spectral reflectance of historical documents offers many advantages. Therefore one method named the Wiener estimation method is applied to estimate the spectral reflectance of historical documents. The Wiener estimation matrix M is determined as follows.[1]

$$M = R_{rv}R_{vv}^{-1} \tag{1}$$

$$R_{rv} = <\boldsymbol{r}\boldsymbol{v}^t> \tag{2}$$

$$R_{vv} = <\boldsymbol{v}\boldsymbol{v}^t> \tag{3}$$

Vector $\boldsymbol{r}$ is the measured spectral reflectance of the Macbeth Color Checker, and vector $\boldsymbol{v}$ is the sensor response including higher order terms when the Checker is taken as a digital image. Matrix R_{rv} is a cross-correlation matrix between vector $\boldsymbol{r}$ and $\boldsymbol{v}$. Matrix R_{vv} is an auto-correlation matrix of vector $\boldsymbol{v}$. The symbol <•> shows the ensemble average, and t shows the transpose of the vector.

Spectral image data $f(x,y,\lambda)$ is calculated from vector $\boldsymbol{v}$ which is a sensor response vector $\boldsymbol{v}$ including higher order of pixel value in the digital image $f(x,y)$ by using the matrix M as follows.

$$f(x,y,\lambda) = M\boldsymbol{v} \tag{4}$$

2.2) Un-uniformity Correction of Illumination

The test sample and a white reference are taken under the same lighting conditions and camera settings. Each pixel value in both digital images is converted from a digital signal to spectral reflectance using the Wiener estimation method, then the un-uniformity is corrected by the following equation.

$$f'(x,y,\lambda) = f(x,y,\lambda)/f_{paper}(x,y,\lambda) \tag{5}$$

In this experiment, conventional printing paper is used as a white reference in accordance with the case-of-use reason cited in the basic requirements.

2.3) Determination of Spectral Component

If a component in the spectral reflectance of the ink used in the historical document is given as prior information, it could provide useful information for extracting the letter area. However, the wavelength $\lambda = 550$ nm is used in this experiment. The image showing single wavelength reflectance is used in the following sections.

3) Processing to Improve Legibility

3.1) Labeling of Letter Area

If we can consider only the frequency response in the imaging system, the taken image $g(x,y)$ is represented from the system response $h(x,y)$ and the original $f(x,y)$ as follows.

$$g(x,y) = h(x,y)*f(x,y) \tag{6}$$

where symbol * means convolution integral. This equation is shown in the Fourier domain as follows.

$$G(u,v) = H(u,v)F(u,v) \tag{7}$$

If the imaging system is shift invariant, $H(u,v)$ is unique. The sharpness difference in $G(u,v)$ is, therefore, caused by a difference in $F(u,v)$. On the other hand, if the sharpness in $F(u,v)$ is constant but the sharpness at the same area in $G(u,v)$ is different, it is referred to as a change in $H(u,v)$.

In the un-sharp masking method, sharp regions such as edge areas are detected by low-pass filtering because sharp areas are more blurred by the low-pass filter than us-sharp areas such as smooth parts in the image. If a different low-pass filter is applied to an image, the different level of sharp areas can be detected. In this experiment the difference means whether the letters are on the front side or the reverse.

The letters written on the reverse side are more blurred than the letters on the front because letters on the reverse side are observed through the paper, which can be referred to as a light scattering layer. This characteristic can be applied to separate the letters on the front or reverse side with the following equation.

$$l'(x,y)=\frac{\Phi^{-1}\left\{H_{\sigma_1}(u,v)F(u,v)\right\}}{\Phi^{-1}\left\{H_{\sigma_2}(u,v)F(u,v)\right\}} \tag{8}$$

where Φ^{-1} is an inverse Fourier transformation, $H_\sigma(u,v)$ is a Gaussian type low-pass filter, which has mean 0 and variance σ^2 as follows.

$$H_\sigma(u,v)=\exp\left(-\frac{\sqrt{u^2+v^2}}{2\sigma^2}\right) \tag{9}$$

In this experiment, $\sigma^2_2 > \sigma^2_1$ is assumed, and its value is σ^2_1 is 1.0 and σ^2_2 is 400.0. The labeling of the letter area is carried out by the following equation.

$$l(x,y)=\begin{cases} front & l^{'}(x,y)\geq t_1 \\ reverse & t_1 > l^{'}(x,y) \geq t_2 \\ paper & otherwise \end{cases} \qquad (10)$$

The threshold t_1 and t_2 are determined experimentally. In this experiment, t_1 and t_2 are 18.0 and 12.0, respectively.

3.2) Hi-pass and Low-pass Filtering

Because the MTF of the human visual system has directional frequency response,[2] a hi-pass filtering method considering the dependency is introduced to obtain a reasonable visual filtering effect without unwanted artifacts after the filtering. In this experiment, the hi-pass filter is defined by the equations as follows where α and β are coefficients to control the filter effects.

$$H_h(u,v)=\alpha-k(w)\exp\left(-\frac{\sqrt{u^2+v^2}}{2\sigma^2}\right) \qquad (11)$$

$$k(w)=1-\beta\left|\sin(2\phi)\right|, \phi = tan^{-1}\left(\frac{v}{u}\right) \qquad (12)$$

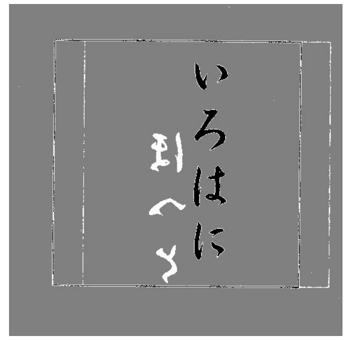
The low-pass filter is determined in this experiment as follows.

$$H_l(u,v)=k(w)\exp\left(-\frac{\sqrt{u^2+v^2}}{2\sigma^2}\right) \qquad (13)$$

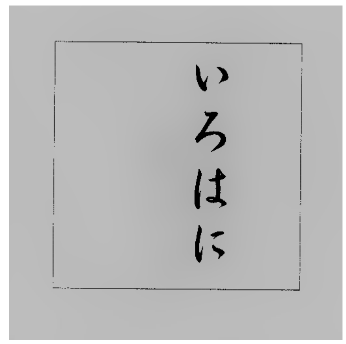
3.3) Synthesis of Filtered Image

The hi-pass filter is used only for the area detected as a target area, and the low-pass filter is affected for the resultant area. Actually the image synthesis process is carried out using the labeling result in a pixel by pixel process. If the labeling image $l(x,y)$ shows the target area, then the pixel value of the hi-pass filtered image is selected as the pixel value of the processed image. On the other hand, if the labeling $l(x,y)$ doesn't show the target area, the pixel value of the low-pass filtered image is selected.

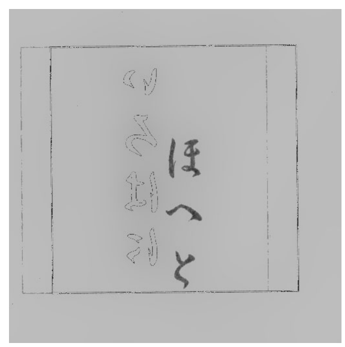
Figure 4(a) shows the result of the labeling. In Figure 4(a), black, white, and gray areas show the front side, reverse side, and other parts respectively. Figure 4(b) and (c) show the results of the synthesis for letters written on the front side and reverse side respectively. Figure 4(c) is mirror inverted.



(a) Result of the labeling.



(b) Extraction of front side letters.



(c) Extraction of reverse side letters. (mirror reversed)

Figure 4. Results of the experiment.

Discussion

The experimental results showed that the designed filters were effective at extracting letters written on the front side of the paper. However, for letters on the reverse side, the contours of letters on the front side were falsely detected as part of the letters on the reverse side. In addition, the thresholds to use in the separation of the letter areas were determined experimentally. An analytical method to determine the thresholds from the results of PSF measurement of the paper[3] is important in future work.

In the proposed application of a method for real historical documents, it is a problem that the surface of the documents is not flat. The un-flat surface will cause a change of blur level in the taken image, therefore a correction method for this un-flat surface is required. In the correction, it would be effective to use information of depth. The method proposed in this experiment has similarity to the Depth from Defocus (DFD) method in the sense of using information of blur level.[4] In the DFD, the depth map is obtained from changes of sharpness in the image, and it is analogous to the method introduced in this experiment. The combination of DFD and the proposed method will be promised.

Conclusions

The basic requirements of a digital imaging system for historical documents were pointed out, and one of them, the legibility of the documents, was improved in this study. However, many things remain to be solved, and the improvement of legibility has to be evaluated quantitatively by historians. Furthermore, a digital imaging system that can get texture information on the surface of the historical documents and high accuracy color information is required for the application of digital imaging systems to historical research. In addition, this application system could be used in galleries at museums as a part of the support system for visitors.

References

1. Norimichi Tsumura, et al, Estimation of spectral reflectance from multi-band images by multiple regression analysis, *Japanese Journal of Optics*, Vol. 27, No. 7, pp. 384-391, 1998 (in Japanese)
2. Tetsuya Ishihara, et al, Dependence of Directivity in Spatial Frequency Response of the Human Eye (2) -Mathematical Modeling of Modulation Transfer Function-, *Journal of The Society of Photographic Science and Technology of Japan*, Vol. 65, No. 2, pp.128-133, 2002 (in Japanese)
3. Chawan Koopipat, et al, Image Evaluation and Analysis of Ink Jet Printing System (I) MTF Measurement and Analysis of Ink Jet Images, *Journal of Imaging Science and Technology*, Vol. 45, No. 6, pp. 591-597, 2001
4. Alex Paul Pentland, A New Sense for Depth of Field, *IEEE Transaction on Pattern Analysis and Machine Intelligence*, Vol. 9, No. 4, pp. 523-531, 1987

Biography

Kimiyoshi Miyata received his ME and Ph.D. degrees in Imaging Science from Chiba University in 1992 and 2000 respectively. After working at Mitsubishi Electric Corporation for 9 years, he joined the Department of Museum Science at the National Museum of Japanese History in 2001. His research interests concern applications of digital imaging studies to museum activities. In 2000 he was awarded the Progressing Award and Itek Award from SPSTJ and IS&T respectively.