A Document Scanner Equalization Technique

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Abstract

Scanned documents/images blur effect is mostly associated with the optics of the scanning system. To reverse this effect, sharpening filters are usually designed to restore blurred images based on ad-hoc pre-determined levels of sharpness. The filter design process is mostly manual, time-consuming, and could provide inconsistent output results among different scanning devices. In this paper, we propose a technique to automatically design an equalizing FIR image filter based on measured blur characteristics of the scanning device. The Slanted-edge technique is used to measure the spatial frequency response (SFR) of the scanning system. The SFR of the equalizing filter (for both horizontal and vertical directions) is composed of two segments: The first segment is the inverse of the measured SFR up to a desired spatial frequency (usually $1/4$ *of the sampling frequency), while the other segment provides an arbitrary gradual attenuation of high frequency noise. The point spread function (PSF) of the equalizing filter is then derived using a 2D frequency sampling filter design method. Ultimately, the cascaded frequency response of the scanning system and the equalizing filter should resemble a perfect SFR (i.e. of unity gain up to a desired spatial frequency and attenuation thereafter) when measured by the slanted edge technique. Our experiments show that this automated process can be applied to different document scanning devices to equalize their spatial frequency response resulting in consistent output sharpness levels.*

Introduction

Scanned documents/images blur effect is mostly associated with the optics of the scanning system. It is highly desirable, in many cases, to reverse this effect. Sharp text and line art constitutes an important aspect of image quality and is one of the goals of many document restoration techniques. To achieve this goal, sharpening filters are usually used to restore blurred images based on ad-hoc pre-determined levels of sharpness. However, the filter design process is mostly manual, time-consuming, and could provide inconsistent output results among different scanning devices.

In this paper, we propose a new technique to automatically restore the sharpness of blurred documents by equalizing the frequency response of a given scanner. Reaching to a common response between different scanners requires a common process to objectively measure scanner characteristics. The slanted edge technique [1] is a standard approach, using a standard test target, to measure the spatial frequency response of cameras and scanners [2, 3]. Based on these measurements, the proposed technique reverses scanner blurring effect by designing equalizing filters that can be used to unify spatial frequency response of different scanners. Our experiments show promising results toward achieving the goal of having automatically equalized scanner responses.

Slanted Edge

The slanted edge technique [1] is a standard technique of measuring the spatial Frequency Response (SFR) of digital imaging devices (cameras or scanners) [4]. It is used in many ISO standards (e.g. [2, 3]) to evaluate the response of different digital imaging devices. It is also used in many other applications to compensate for the scanner response in some techniques that rely on scanners as a data acquisition device [5]- [8], or to measure the scanner color misregistration [9].

The slanted edge technique uses a specific target that has skewed edges. A super-resolved line spread function can be extracted from the slanted edge in the test target, followed by a filtering step to extract the point-spread function. The FFT technique is then used to extract the spatial frequency response from the point-spread function.

In this paper, we used the Gaussian curve fitting technique (as in [7]) to reduce the noise effect on the measured SFR's. The Gaussian fitting equations can be described as:

$$S_u(u) = \alpha_u \exp\left(-\frac{u^2}{\sigma_{u_1}^2}\right) + (1-\alpha_u)\exp\left(-\frac{u^2}{\sigma_{u_2}^2}\right), \quad (1)$$

for the horizontal SFR, and

$$S_v(v) = \alpha_v \exp\left(-\frac{v^2}{\sigma_{v_1}^2}\right) + (1-\alpha_v)\exp\left(-\frac{v^2}{\sigma_{v_2}^2}\right), \quad (2)$$

for the vertical SFR. We use the Nelder-Mead simplex optimization technique to find the parameters α_u, $\sigma_{u_1}^2$, $\sigma_{u_2}^2$ for the horizontal SFR and α_v, $\sigma_{v_1}^2$, and $\sigma_{v_2}^2$ for the vertical SFR, independently. Examples of the fitting parameters and the resulting SFRs are shown for the horizontal direction in Figure 1 (top), and the vertical direction in Figure 1 (bottom).

Equalization Filter

In this section, the scanner equalization technique is described. Starting from the measured SFR of the scanning device, our goal is to design an equalizing filter so that the combined SFR of the equalizing filter and the scanner resembles a perfect SFR (i.e. unity from frequency 0 up to a desired frequency with gradual attenuation hereafter).

To get the unity section, the equalizing filter response should be the inverse of the original SFR of the scanner within that section. We chose the frequency band of the unity section to be 0 to $f_s/4$, where f_s is the spatial sampling frequency. The attenuation section is chosen to be a linear attenuation such that the frequency response reaches 0 at $f_s/2$. Both the horizontal and vertical frequency responses of the equalizing filter can be formu-

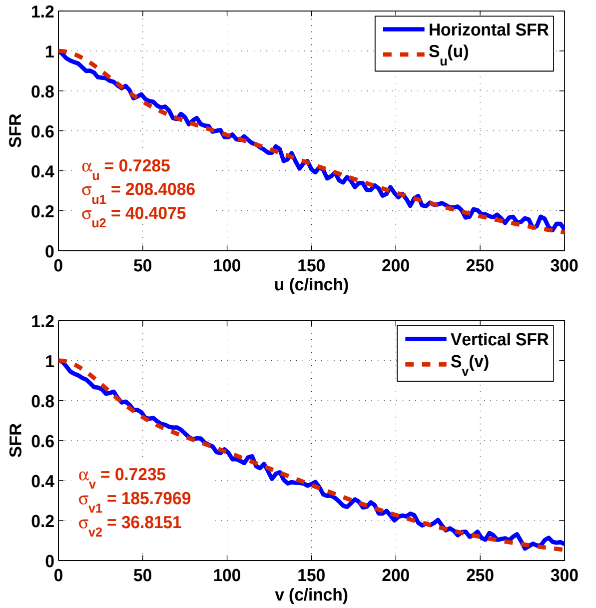

Figure 1. *Scanner SFRs measured using the slanted edge technique with the corresponding fitting curves using a mixture of two Gaussians. The horizontal scanner SFRs (top). The vertical scanner SFRs (bottom).*

lated as follows.

$$H_u(u) = \begin{cases} \frac{1}{S_u(u)}, & 0 \le u \le u_s/4; \\ m_u(u - u_s/4) + \frac{1}{S_u(u_s/4)}, & u_s/4 \le u \le u_s/2; \end{cases} \quad (3)$$

where u_s is the horizontal spatial sampling frequency and m_u is defined as:

$$m_u = \frac{4}{u_s}(k_u - \frac{1}{S_u(u_s/4)}),$$

where k_u is an arbitrary constant defines the value of H_u at $u = u_s/2$. In our analysis we use $k_u = 0$ which reduces m_u to:

$$m_u = -\frac{4}{u_s S_u(u_s/4)},$$

and $H_u(u)$ to:

$$H_u(u) = \begin{cases} \frac{1}{S_u(u)}, & 0 \le u \le u_s/4; \\ -\frac{4u}{u_s S_u(u_s/4)} + \frac{2}{S_u(u_s/4)}, & u_s/4 \le u \le u_s/2; \end{cases} \quad (4)$$

A similar derivation of the vertical response can be written as:

$$H_v(v) = \begin{cases} \frac{1}{S_v(v)}, & 0 \le v \le v_s/4; \\ -\frac{4v}{v_s S_v(v_s/4)} + \frac{2}{S_v(v_s/4)}, & v_s/4 \le v \le v_s/2; \end{cases} \quad (5)$$

where v_s is the vertical spatial sampling frequency.

Both H_u and H_v are then sampled (typically 64 samples in each direction) to design the equalizing filter. A zero phase 2D equalizing filter can be derived from the horizontal and vertical frequency samples [10]. First, the magnitude of the 2D frequency response is derived by interpolating between horizontal and vertical samples on an elliptical grid. The inverse 2D FFT is then used to generate the point spread function of the filter. Figure 2 shows examples of 1D profiles (Figure 2 (top) for horizontal and (bottom) for vertical) of the frequency samples and the corresponding designed filter. Figure 2 also shows the desired SFR and the measured SFR after convolving the equalizing filter with the original slanted edge image.

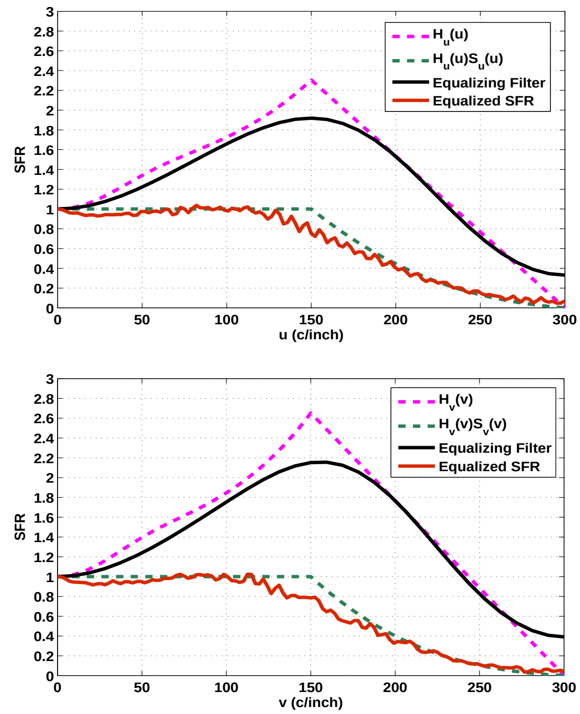

Figure 2. *Equalized scanner SFRs corresponding to Figure 1 using the proposed equalization technique. The figures show both the desired equalizing filter frequency response $H_u(u)$ ($H_v(v)$) and the desired SFR, $H_u(u)S_u(u)$ ($H_v(v)S_v(v)$) compared with their actual horizontal response, top (vertical response, bottom).*

Experimental Results

In this section, we provide two experiments to show the effect of the equalization process on blurry scanned documents. The first experiments examines four different test scanners. Their SFR's are measured using the slanted edge technique, then equalizing filters are designed using the proposed technique. The individual equalizing filters are applied to the corresponding slanted edge images of the corresponding scanners to get the equalized SFR's.

Figure 3 shows the horizontal and vertical SFR's of the test scanners before and after the equalization. As shown in Figure 3 (a) the horizontal SFR's are similar for the test scanners while Figure 3 (b) shows that scanner C has higher SFR than the other scanners in the vertical directions. Applying the equalization procedure, the four SFR's of the examined scanners, both horizontal and vertical, have been normalized with similar characteristics as shown in Figures 3 (c) and (d). Figures 4 (a), (b), (c), and (d) show results from scanners A, B, C, and D respectively. The upper row of the figure shows the original text images, while the second row shows the equalized images having similar quality among different scanners. The bottom row of the figure shows the used equalizing filters which reflects the fact that scanners A, B, and D had

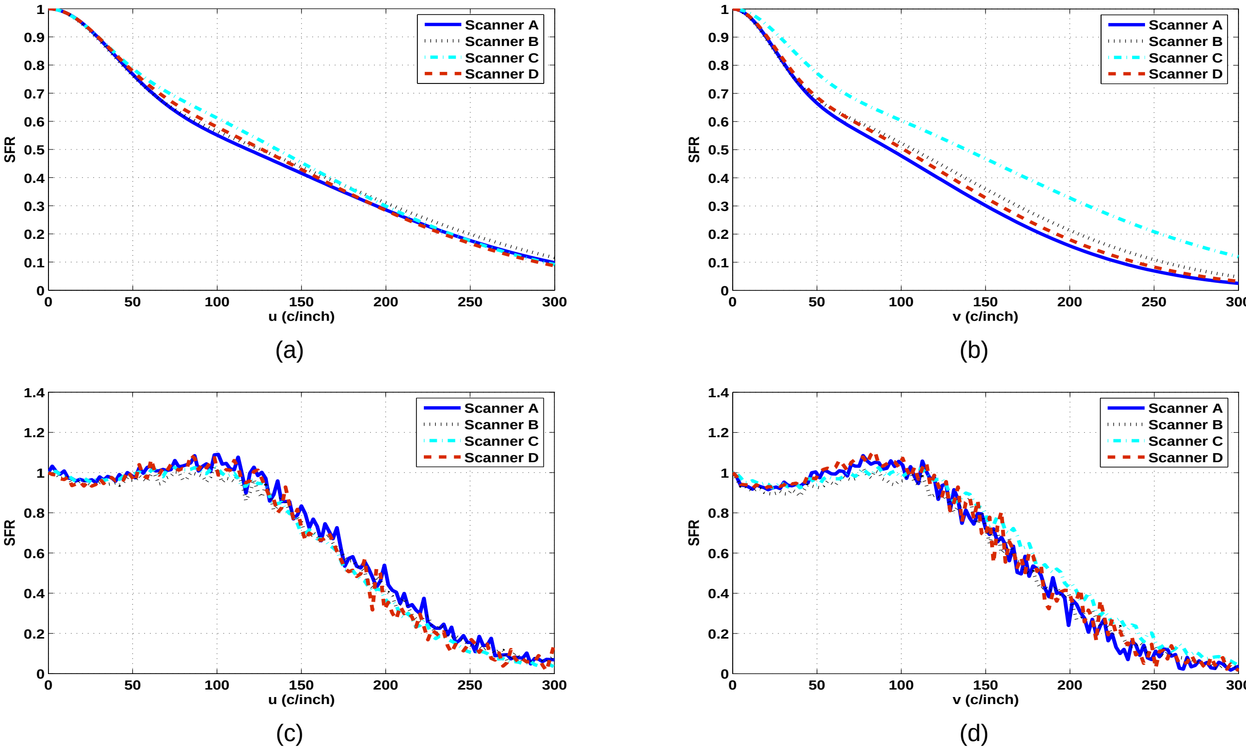

Figure 3. *Equalized SFR's. (a) the original horizontal SFR's of 4 different scanners, (b) the original vertical SFR's for the same scanners, (c) the equalized SFR's corresponding to ones in (a), and (d) the equalized SFR's corresponding to ones in (b)*

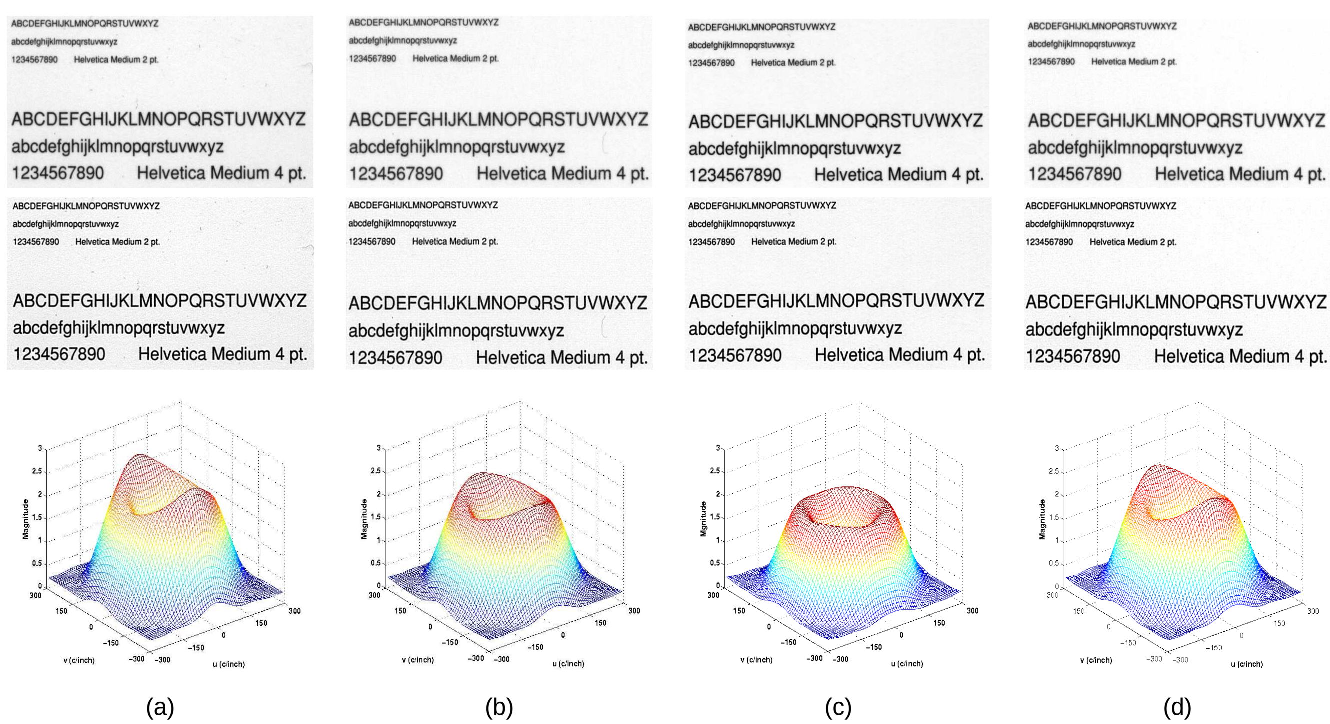

Figure 4. *Document restoration. Top row, examples for images to a document scanned by 4 different scanners. Middle row, images after applying scanner equalization. Bottom row, the 2D frequency response equalizing filters for each scanner; (a) scanner A, (b) scanner B, (c) scanner C, and (d) scanner D.*

dissimilar horizontal and vertical SFR's that needed asymmetric equalizing filters compared to the equalizing filters of scanner C.

In the second experiment, we show results from scanner B where we use different filters cascaded with equalizing filter to vary the sharpness levels. A number of 12 filters with different gain and attenuation are convolved with equalizing filter and applied to a test image as shown in Figure 5. The corresponding sharpness metric [11] is summarized in Table 1. In addition, we applied these filters to the slanted edge image scanned by scanner B, and measured the modified SFR as shown in Figure 6. Comparing Figures 5 and 6, and the sharpness metric from Table 1, there are good correlations between the sharpness levels measured by the sharpness metric, the corresponding SFR's and the visual assessment of the sharpness as seen from the corresponding images.

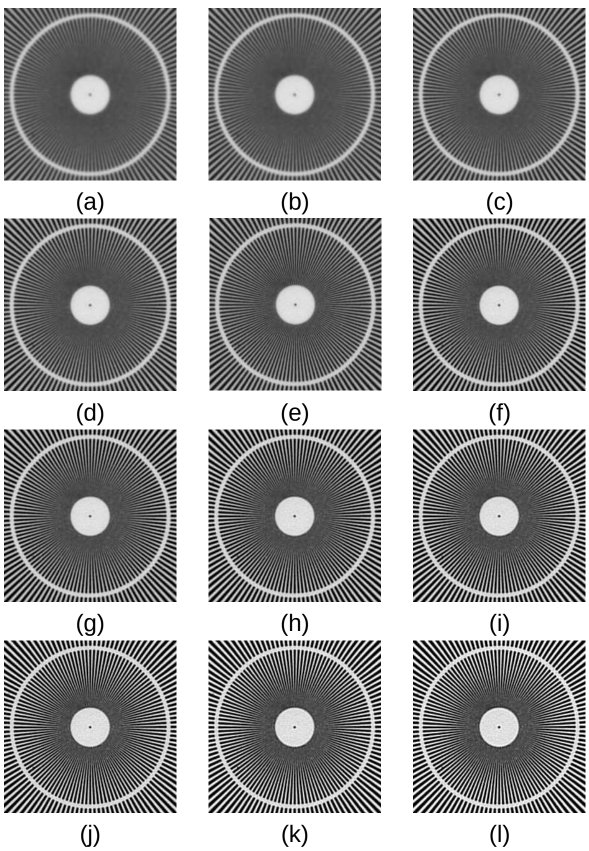

Figure 5. *Changing the sharpness level by applying different gains and attenuations to the equalizing filter of scanner B.*

Table 1. Sharpness levels measured after applying different gains and attenuations to the equalizing filter response.

Figure 5	(a)	(b)	(c)	(d)	(e)	(f)
Sharpness	19.4	20.1	21.5	23.4	24.9	27.9
Figure 5	(g)	(h)	(i)	(j)	(k)	(l)
Sharpness	30.7	36.0	40.4	44.3	46.2	49.2

Conclusions

In this paper, we introduced a new technique to automatically restore the edge sharpness of scanned documents. The proposed technique requires measurements based on the slanted edge approach. Based on that measurements we design equalizing filters to invert the blurriness effect due to the scanning process. Experiments results show promising performance of the proposed technique in sharing similar sharpness characteristics and spatial frequency responses among different scanners.

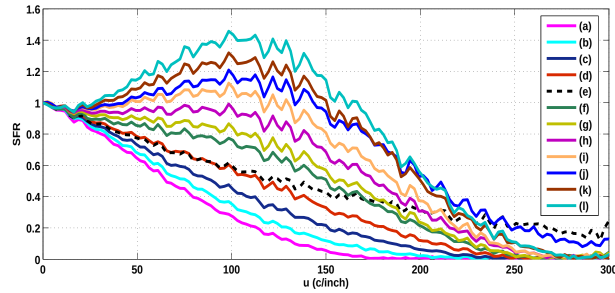

Figure 6. *Varying SFR of scanner B by applying different gains and attenuations to the equalizing filter applied to the slanted edge image, then measuring the resulting SFR's.*

References

[1] Reichenbach, S., Park, S. and Narayanswamy, R., 1991. "Characterizing digital image acquisition devices," *Optical Engineering* 30(2), pp 170- 177.

[2] ISO 12233-1, *Photography - Electronic still-picture cameras - Resolution measurements*, ISO (2000).

[3] ISO 16067-1, *ISO 16067-1:2003 Photography - Spatial resolution measurements of electronic scanners for photographic images - Part 1: Scanners for reflective media*, ISO (2003).

[4] P. D. Burns,"Slanted-Edge MTF for Digital Camera and Scanner Analysis," *Proc. IS&T 2000 PICS Conference*, pp. 135-138, 2000.

[5] Woonyoung Jang, and Jan P. Allebach, "Characterization of Printer MTF," *Journal of Imaging Science and Technology* 50(3): 264-275, 2006.

[6] Nicolas Bonnier, and Albrecht J. Lindner, "Measurement and compensation of printer modulation transfer function," *J. Electronic Imaging* 19(1), 011010 (Jan-Mar 2010).

[7] S. H. Kim, J. P. Allebach, "Optimal unsharp mask for image sharpening and noise removal," *J. Electronic Imaging* 14(2), 023005 (Apr-Jun 2005).

[8] Bang, Y., Kim, S. H., and Choi, D. C., "Printer resolution measurement based on slanted edge method," *Proceedings of the IS&T/SPIE Electronic Imaging Conference, Image Quality and System Performance V*, Farnand, S. P. and Gaykema, F., eds., 680807-680815, SPIE (2008).

[9] P. D. Burns and D.Williams, "Using slanted edge analysis for color registration measurement," *IS&T PICS Conference*, pp 51-53, Savannah, Georgia, April 1999.

[10] Jae S. Lim, *Two-Dimensional signal and image processing*, Prentice Hall Inc., 1990.

[11] Rony Ferzli and Lina J. Karam,"A No-Reference Objective Image Sharpness Metric Based on the Notion of Just Noticeable Blur (JNB)," *IEEE Transactions on Image Processing*, vol. 18, no. 4, April 2009.