Proceedings of the 5th WSEAS International Conference on Applied Computer Science, Hangzhou, China, April 16-18, 2006 (pp1020-1023)

A Novel Method to Determine Scanner Parameters (PSF)

LONGJIANG YU and SHENGHE SUN
Automatic Test and Control
Harbin Institute of Technology
P.O.Box 339, Xidazhi Street 92
P.R.China

Abstract: - The process of printing and scanning is one of the most difficult problems not to be solved in the field of digital watermarking, because of lack knowledge of their nature. This paper focuses on the process of scanning. A novel method to determine scanner attack model parameters, i.e. Point Spread Function (PSF) is proposed in this paper. Compared with a standard method, the advantage of this proposed method is to acquire a complete two-dimensional PSF profile. Experimental results show that the proposed method is efficient to simulate the process of scanning.

Key-Words: - Digital watermarking, Print-and-scan model, Print-and-scan attack, Point spread function, Line spread function, Edge spread function, Optical transfer function, Optical test and measurement.

1 Introduction

The success of the Internet introduces a new set of challenging problems regarding security. One of many issues that have arisen is the problem of the copyright protection. Digital watermarking is proposed as a way to claim the ownership of the source and owner [1]. However, there are some open problems in digital watermarking. Print and scan attack is one of the most difficult problems.

Possible solutions as the whole strategy against print-and-scan attack are presented recently [2][3]. Voloshynovskiy et al. [2] has tried to solve this problem for inkjet printing and scanning. In this paper, a mathematical model of printing is proposed, with the assumption that scanning does not introduce any distortions. But in more general case one need to take into account the effect of scanning because of some optical blurring and aberrations as well as sensor non-linearity. In the other hand, Yu et al. [3] cope with the process of laser-jet printing and scanning. The operation of scanning is considered as a function of Gaussian blur. Then how to determine the parameters of the function is crucial for the practical use of watermarking in print-and-scan scenario.

So far some methods have been proposed to cope with optical blurring of a scanner. Glasbey etc. [4] propose a method to acquire the blurring function of a document scanner by using a piece of black-white text. The blurring function is estimated from the ratios of the Fourier amplitudes of the blurred text image and its binary version by thresholding, which is considered as a close approximation to the original text image. The efficiency of this method is limited by the quality and content of scanned text. In [5]-[8], a scanner model for blurring is formulated as a Point Spread Function (PSF) for the application of Optical Character Recognition (OCR). The PSF is inspected only from bi-level image for OCR application scenario, which is more difficult to determinate the PSF than grayscale scan. So only two parameters of the PSF, the width of PSF and the threshold for binarization, can be estimated in this case. It is considered enough for OCR [5] but is not for exactly modeling optical blurring of a scanner.

On the other hand, some methods select an indirect way to derive PSF in frequency domain. Gennery [9] proposes a method to determinate Optical Transfer Function (OTF), the Fourier transform of PSF, by inspection of log-power spectrum of the blurred image to locate the zero crossings, which are characteristic to of the unknown PSF. A bispectrum-based method proposed in [10] demonstrates better than the method of [9] at low signal-to-noise ratios. Both of methods are restricted to certain types of parametric PSF that are completely characterized by the location of zeros in their Fourier transforms. Such blurs as the 1-D uniform motion blur (modeled by a box-car PSF) and the out-of-focus blur (modeled by a uniform PSF over a 2-D circular support) belong to this class. But the PSF of a scanner is proven not this kind of blur but a 2-D Cauchy function as [4] shown. Modulation Transfer Function (MTF), the magnitude of OTF is determined in [11][12]. But PSF is not derived from MTF without Phase Transfer Function (PTF), the phase of OTF. In [13] the 1-D slice of PSF, a.k.a. Linear Spread Function of a film can be estimated from its Edge Spread Function (ESF). The LSF is formulated as a truncated series of Hermite polynomials multiplied

Proceedings of the 5th WSEAS International Conference on Applied Computer Science, Hangzhou, China, April 16-18, 2006 (pp1020-1023)

by a Gaussian function. The coefficients of Hermite polynomials and the parameters of the Gaussian function are estimated from the system of equations between LSF with unknown parameters and the measurement of ESF. The estimation is converted as a problem of non-linear least square (NNLS), for the presence of Gaussian function. This method is adapted to determinate the PSF of a scanner in this paper. Another method based on standard ISO slant-edge analysis for spatial resolution measurements of scanners is adapted to derive the PSF of a scanner for comparison. Details of this ISO test steps can be found in [14]-[16].

2 PSF Based Scanner Model

A scanner is an analog-digital converter from hardcopy to digital image. In most document scanners, a white light source projects light onto hardcopy placed on flat bed of the scanner. Some optical lens collect the light reflected by hardcopy and transfer the quantity of light to Charge-Coupled Device (CCD) sensors. These sensors convert light energy to electrical energy, and some associated circuits accomplish the process of discretization and quantization to form digital images.

Based on the above mechanism, a scanner can be considered as an incoherent optical system. This system function is also called Point Spread Function (PSF). Let $g(x,y)$ be the image function resulted from scanning an object in 2-D image space, the scanning process can be formulated as a convolution between original image function $f(x,y)$ and PSF of the scanner $h(x,y)$, as the following equation,

$$g(x,y) = h(x,y) * f(x,y) \quad (1)$$

For an optical system, determination of its PSF is necessary in practical use.

2.1 Mathematical derivation of LSF

In this method scanner's LSF is approximated as a parametric form to describe certain scanner mathematically. Based on the method in [13], the noise free line spread function is modeled as the first n terms in a Hermite series of polynomials as the following equation.

$$g(z) = f(z)\sum_{i=0}^{n} c_i H_i(z) \quad (2)$$

$$z = \frac{x-\mu}{\sigma};$$

$$f(z) = \frac{1}{\sqrt{2\pi}}\exp\left\{-\frac{z^2}{2}\right\},$$

$$H_0(z) = 1; \qquad H_1(z) = z,$$

$$H_2(z) = z^2 - 1; \quad H_3(z) = z^2 - 3z; etc.$$

In equation (2), x is distance along scanned direction, i.e. perpendicular to the edge, g(x) is line spread function, n is number of terms in the Hermite polynomial expansion, μ is pixel location of edge on scan, σ is positive normalizing scale factor.

The Hermite polynomials from a basis for real square integrable functions, therefore any line spread function can be accurately represented by making n sufficiently large. Tested edge response is integrated analytically to establish a relation between ESF and LSF as the following equation.

$$G(z) = \int_{-\infty}^{z} g(z)dz = c_0 F(z) - f(z)\sum_{i=0}^{n-1} c_{i+1} H_i(z) \quad (3)$$

In equation (3), G(x) is edge spread function, F(x) is the error function.

To determine these unknown Hermite coefficients c_i and Gaussian function parameters (μ and σ) can be implemented by minimizing

$$J = \sum_{i=1}^{N}\left[M_i - f(z_i)\sum_{i=0}^{n} c_i H_i(z_i)\right] \quad (4)$$

$$z_i = (i\Delta - \mu)/\sigma$$

where N is number of pixels, M_i is measured intensity at x_i, Δ is distance between pixels.

The differentiation of ESF leads to decrease of signal-to-noise ratio need to compensate. So this method is to determine LSF in an indirect way according to the conversion,

$$\frac{d}{dx}ESF(x) = LSF(x) \Leftrightarrow ESF(x) = \int_{-\infty}^{x} LSF(u)du \quad (5)$$

which leads to solve a complex inverse problem, where x is the space variable with the direction perpendicular to the edge. The LSF is represented as a truncated series of Hermite polynomials multiplied by a Gaussian function. The coefficients of Hermite polynomials and the parameters of the Gaussian function are estimated from the system of equations between formulated LSF with unknown parameters and the measurement of ESF. The number of equations in the system of equations between LSF with unknown parameters and the measurement of ESF is greater than the number of Hermite coefficients (in [13] 4 to 6 is considered enough) and the number of parameters in Gaussian function (μ and σ). So this system of equations is overdetermined. In this case there are contradictions in the system of equations and it is impossible to acquire precise solutions. Approximate solutions of precise solutions are evaluated using least square method. This problem is a non-linear problem because of the presence of the Gaussian parameters. Moreover, almost no apriori knowledge of unknown parameters in the system of equations adds up the difficulty in solving this problem, which is not suitable for classical methods such as the well-known Levemberg-Marquardt algorithm [17]. So the VARPRO (variable projection) approach [18] is used here. When the parameters are settled, a mathematical form of LSF in certain direction is determined. Interpolating with LSF on different direction constructs the whole profile of the 2-D PSF.

3 Experimental Results

A consumer-grade flatbed scanner HP scanjet 3570 is used to scan a monochrome (black and white) edge pattern (shown in Fig. 1) in 600dpi (dot per inch) printed on glossy photographic paper by a laser image setter Esko DotMate 7500P in 3600dpi.

As seen in Fig.1, the edge pattern is placed into a rectangular black frame. This frame is not in actual image used in experiments. It is only to discriminate the image here conveniently.

This image pattern is rotated from 0 to 360 degrees in step of 1 degree and scanned during each step. LSF in each scanned direction is acquired from each step. Then the 2-D curve PSF is constructed by interpolating each LSF with the routine of [19] respectively.

For comparison with the standard ISO method, a slant edge scanner target [20], a product of Applied Image Inc., is used. A Matlab executable program [21] is adopted to analyze the scanned results for the acquisition of PSF.

Experimental results verify that the two methods can acquire the PSF of the scanner close to each other, as shown in Fig.2, where data1 is test results of proposed method, and data2 is the test results of ISO method acquired before the operation of Fourier transform. Those results are both sampled from the direction of scanning (The results of vertical direction of scanning is so close to those of scanning direction that one could almost not distinguish them. So they are not given here). However, the advantage of proposed method is to acquire a complete two-dimensional PSF profile, rather than only two directions obtained from the ISO method. In addition, mathematical expression of PSF derived from the proposed method is convenient in deconvolution. One can make tested scanner's PSF deconvolved with scanner's output blurred images to recover the image.

References:

[1] Wolfgang, R. B., Podilchuk, C. I., and Delp, E. J., Perceptual Watermarks for Digital Images and Video, Proceedings of the IEEE, July 1999, **87** (7), pp.1108-1126.

[2] Voloshynovskiy, S., Koval, O., Deguillaume, F. and Thierry, P., Visual communications with side information via distributed printing channels: extended multimedia and security perspectives, Proc. SPIE Vol. 5306, Security, Steganography, and Watermarking of Multimedia Contents VI, Jun 2004, pp. 428-445.

[3] Longjiang Yu, Xiamu Niu, Shenghe Sun. Print-and-scan model and the watermarking countermeasure. Image and Vision Computing, Volume 23, Issue 9, September 2005, pp. 807-814.

[4] C. A. Glasbey, G. W. Horgan, and D. Hitchcock, A note on the grey-scale response and sampling properties of a desktop scanner, Pattern Recognition Letters, vol. 15, no. 7, pp. 705-711, 1994.

[5] Tin Kam Ho and Henry S. Baird, Large-Scale Simulation Studies in Image Pattern Recognition, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 19, No. 10, October 1997, pp. 1067-1079.

[6] Barney Smith, E. H., Characterization of Image Degradation Caused by Scanning, Pattern Recognition Letters, Volume 19, Number 13, 1998, pp.1191-1197.

[7] Barney Smith, E. H., Estimating Scanning Characteristics from Corners in Bilevel Images, Proc. SPIE Document Recognition and Retrieval VIII, Vol. 4307, San Jose, CA, 21-26 January 2001, pp.176-183.

[8] Barney Smith, E. H., Bilevel Image Degradations: Effects and Estimation, Proc. 2001 Symposium on Document Image Understanding Technology, Columbia, MD, 23-25 April 2001, pp. 49-55.

[9] Gennery, D. B., Determination of Optical transfer function by inspection of the frequency domain plot, Journal of the Optical Society of America, Vol. 63, No. 12, December 1973, pp. 1571-1577.

[10] Chang, M., A., Tekalp M., Erdem, A. T., Blur Identification using the Bispectrum, IEEE

Trans. Signal Processing, Vol. 39, October 1991, pp. 2323-2325.
[11] Simonds, R. M., Two-dimensional modulation transfer functions of image scanning systems, Applied Optics, Vol. 20, No. 4, February 1981, pp. 619-622.
[12] Wong, H., Effect of knife-edge skew on modulation transfer function measurements of charged couple device imagers employing a scanning knife edge, Optical Engineering, Vol. 30, No. 9, 1991, pp. 1394-1398.
[13] Smith, P. L., New Technique for Estimating the MTF of an Imaging System from its Edge Response, Applied Optics, Vol. 11, No. 6, June 1972, pp. 1424-1425.
[14] P. D. Burns and D. Willliams, Using slanted edge analysis for color registration measurements, Proc. PICS Conference, IS&T, pp. 51-53, 1999.
[15] P. D. Burns, Slanted-edge MTF for digital camera and scanner analysis, Proc. PICS Conf., IS&T, pp. 135-138, 2000.
[16] P. D. Burns and D. Willliams, Refined slanted-edge measurements for practical camera and scanner testing, Proc. PICS Conf., IS&T, pp. 191-195, 2002.
[17] J. J. Moré, The Levenberg-Marquardt algorithm: implementation and theory, Numerical Analysis, ed. G. A. Watson, Lecture Notes in Mathematics 630, Springer Verlag, pp 105-116, 1977.
[18] G. Golub and V. Pereyra, Separable nonlinear least squares: the variable projection method and its applications, Institute of Physics Publishing, Inverse Problems 19, pp. R1-R26, 2003.
[19] P. Thevenaz, Interpol.c, a C routine for 2D-interpolation, available at http://www.bigwww.epfl.ch/, 2002.
[20] A-62-SFR-P-RP, Slant edge target, Applied Image Inc., available at http://www.aig-imaging.com/targets_QA.html#QA-62.
[21] Slant Edge Analysis Tool sfrmat 2.0 (For ISO 12233 - Resolution Measurement), Matlab function, available at http://www.i3a.org/downloads_iso_tools.html, Aug. 2003.

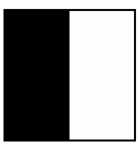

Fig. 1. Scanner's PSF test target for the proposed method in this paper.

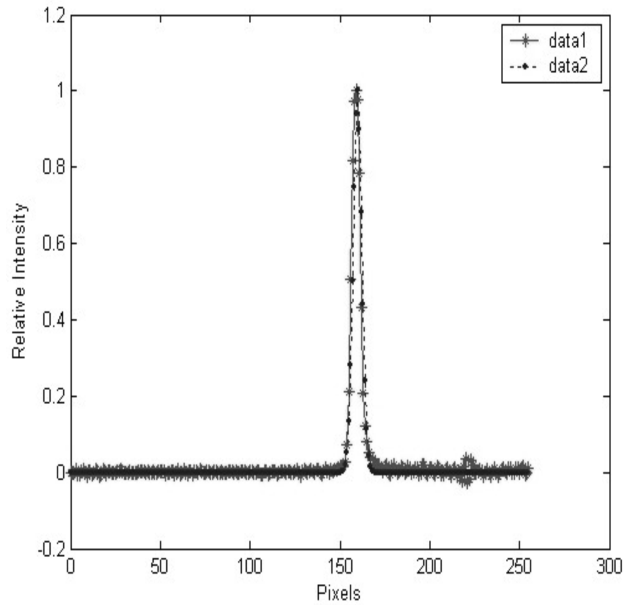

Fig. 2. Scanner's PSF test results from proposed method and ISO method.