Utilizing Flatbed Scanners to Measure Printer Motion Quality Error

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Abstract

This paper assesses the viability of using a flatbed scanner to measure motion quality of a printer. The procedure utilizes previously printed reference marks from a high quality printer next to which a ladder chart of a given frequency is printed on the machine to be measured.

The resultant print sample is scanned and processed to obtain centroid locations. A correction is applied to the printer positional error prior to Fourier analysis. This paper will investigate the accuracy of this method in determining positional errors incurred and removing scanner contribution.

Introduction

The motion quality of a printer is a measure of its capability to precisely place a pixel. Poor motion quality may result in objectionable banding defects for the customer. In xerographic systems, the focus is on the motion quality of the laser beam to photoreceptor interface. Of utmost concern is the periodic nature of this variation, available by Fourier analysis. A test image containing a series of equally spaced lines, or ladder pattern is printed, and the resultant reflectance profile is analyzed to determine the line centroids. The centroids are compared to a theoretical reference and the resultant is termed positional error. This error signal is Fourier analyzed and the resultant error amplitude is plotted against spatial frequency, given in units of cycles per millimeter (cyc/mm). The peak disturbances are identified and compared to subsystem critical parameters. Listed below are some potential sources of error for office printers:

- Photoreceptor velocity controller
- Structural vibration
- Laser polygon motor wobble
- Laser polygon speed controller
- Gear noise in the paper path
- Once around of eccentric components
- Paper feed to inkjet head speed match

The spectrum is compared to the design element excitation frequencies to determine root cause. This is a powerful technique for diagnosis of printer condition.

What are the requirements for making motion quality measurement and will the flatbed scanner meet them? Three major characteristics are cited:

Motion Quality of Measurement System

There should be confidence that the measured amplitude of positional error is caused by the printer and not the measurement system. The spectrum of the measurement device, investigated later in this paper, will prove to be excellent over most frequencies of interest.

MTF of Measurement System

A Nyquist frequency of 2-3 cyc/mm is reasonable for assessing the printers' motion quality. The human visual system is most sensitive ~1cyc/mm (400 mm viewing distance) and most printer component excitation frequencies are <3 cyc/mm. A flatbed scanner therefore should be able to resolve twice the Nyquist frequency, or 4-6 cyc/mm. The scanner tested has MTF(4 cyc/mm) = 0.76 and MTF(6 cyc/mm)=0.60. This level of performance is acceptable for the centroid detection algorithm since the amplitude of the profile is not critical. Care should be taken to present the scanner with approximately 50%AC targets. Although the bitmap is designed at 50%AC, the marking process may grow the lines, resulting in a higher %AC output print. This may result in discontinuities in the white spaces between ladder marks, and algorithmic errors in detecting location. This problem has been observed in evaluation of line growth characteristics of some printers, but may be corrected by redesigning the test target with reduced area coverage.

Sampling Resolution of Measurement System

To obtain a smooth reflectance profile and minimize interpolation, the sampling resolution of the measurement device should be such that the waveform is sampled at least 8 times per period. This characteristic is satisfied with a 1200 spi input scanner. To achieve the 2-3cyc/mm Nyquist criteria, ladder charts are designed at 4-6 cyc/mm, and sampled at 1200 spi. This results in approximately 8-12 samples per period, sufficient for this application.

Utilizing a flatbed scanner for measuring printer motion quality is also desirable because of the quick turnaround time, low expense, and the many other image quality metrics available to scanner based image quality measurement systems.[1,2] The following experiment investigates the contribution of the measurement system to the overall measurement of motion quality of the printer and more importantly, applies a correction to improve the measurement.

Experiment

Three image samples, described in **Table 1**, were used in this experiment.

Table 1. Targets selected for experiment come from two printers and one high quality reference.

Sample ID	Ladder Chart Pattern	Printer Resolution (dpi)	Ladder frequency (cyc/mm)
Printer 1 (P1)	1 on : 2 off	300	3.94
Printer 2 (P2)	1 on : 3 off	600	5.91
Litho (REF)	50%AC	N/A	5.0

The three samples are placed on the scanner, oriented parallel to the scan direction, as shown in **Figure 1**, and scanned at 1200 spi. The CCD array must be oriented perpendicular to the lines on the ladder chart. If the sample were rotated, the sampling would occur in the scan direction, introducing motion error from the scanner's stepper motor on the measurement.

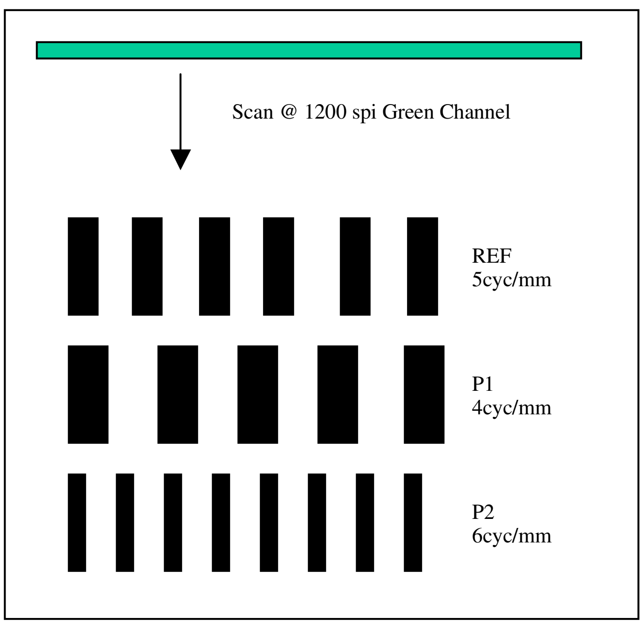

Figure 1. Illustration of samples and scan orientation. The scanner output is a 1200 spi (8-bit) grayscale TIFF image

The image crop length (191.28 mm) by width (4.23 mm) is analyzed with an algorithm that divides the image into several scans, applies deskew correction, and returns an array of line centers. Some statistical results are shown in Table 2 Data Analysis and Observations.

Table 2. Statistical results of ladder chart measurements. Data Analysis and Observations

	REF	Printer1	Printer2
N (# lines)	962	753	1119
$\Delta X_{AVG\ (um)}$	198.77	253.95	170.92
$\Delta X_{INPUT\ (um)}$	200	254	169.2
MAG	0.9939	0.9998	1.0094
$N\Delta X$ (mm)	191.2	191.2	191.2
$f_{NYQ\ (cyc/mm)}$	2.52	1.97	2.93

With image size ($N\Delta X$) constant, the samples with higher Nyquist frequencies (f_{NYQ}) will have more lines (N) within the image. The magnification is the ratio of the average measured line spacing to the expected line spacing, $\Delta X_{AVG\ (um)} / \Delta X_{INPUT\ (um)}$. Note this calculation does not take into account the flatbed scanner actual resolution. The positional error, including system (printer and scanner) magnification effects is as follows:

$$ERR(i) = X_i - X_0 - \Delta X_{INPUT} * i \quad (1)$$

where the index i=0, 1, …, N-1. From the i^{th} centroid location X_i, subtract the first centroid location, X_o, then subtract the theoretical input spacing multiplied by the index. The positional error results are displayed in **Figure 2**.

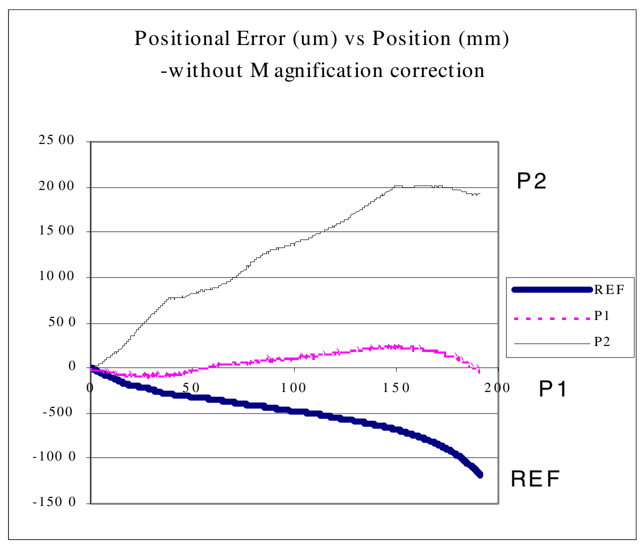

Figure 2. Positional error relative to theoretical line center

The P2 sample exhibits the largest magnification error, enlarging approximately +2mm, whereas the REF sample is reduced approximately 1.2 mm. Note the unexpected nonlinear behavior for each sample. This method of calculating the positional error is useful for observing the combined level of magnification in the printer and measurement system. However, this is not associated with the periodic variation, so a new error calculation is employed.

To eliminate the effect of magnification errors, the positional error is calculated relative to the average line spacing as follows:

$$ERR(i) = X_i - X_0 - \Delta X_{avg} * i \qquad (2)$$

This technique will remove system magnification, as well as setting the error to zero at i=0 and i=N-1 endpoints. This benefit of this property is that no windowing is necessary for spectral analysis. The resulting traces are illustrated in Figure 3.

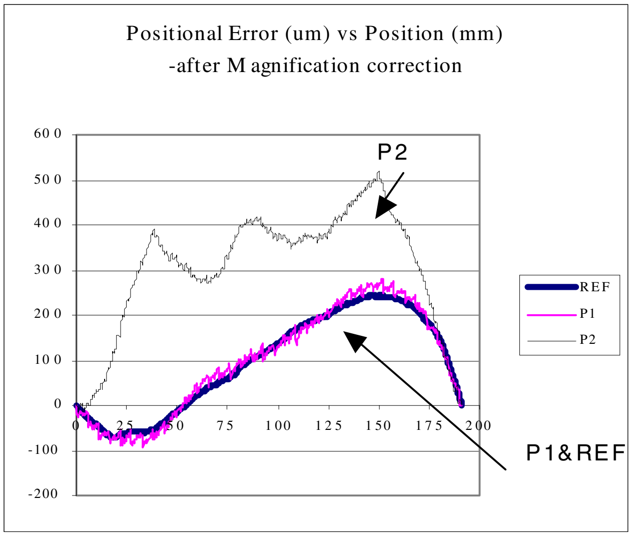

Figure 3. Positional error result after correction for magnification.

Note the similarity between P1 and REF samples and the distinctly different P2 sample. To determine the source of the error (is it the scanner or target?), the REF sample was scanned on a very high quality scanner (HQ) and the positional errors compared in Figure 4. These results indicate that the scanner is the source of a large amplitude (~150 um) low frequency error, possibly due to sensor bar warpage or bow.

To eliminate the error of the measurement system, the following method is applied. For the given printer's i^{th} centroid position, calculate the reference error as follows:

a) Threshold the array of reference centroids, resulting in a fractional index, f_i.

b) Using the fractional index, interpolate the array of reference errors, returning the reference error at the printer centroid location.

c) Compute the corrected positional error as follows:

$$ERR(i) = Printer\ Error(\ i) - Reference\ Error(i) \qquad (3)$$

The correction is applied to P1 and P2 and displayed in Figures 5 & 6. Note the dramatic difference after correction is applied.

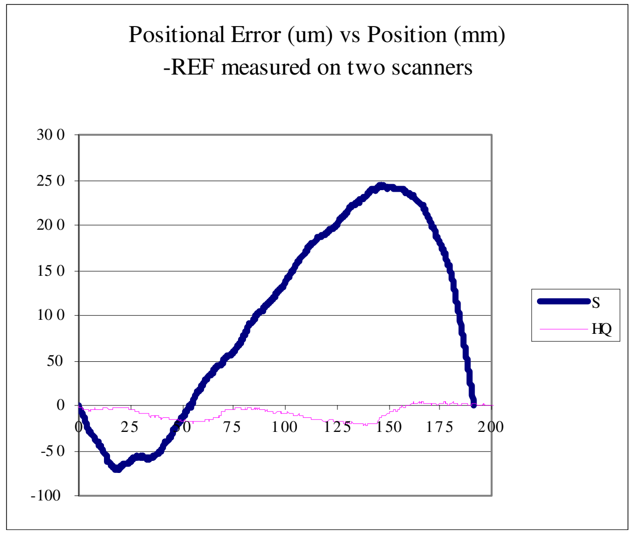

Figure 4. REF target error measured on 2 scanners; nominal(S) and very high quality scanner (HQ).

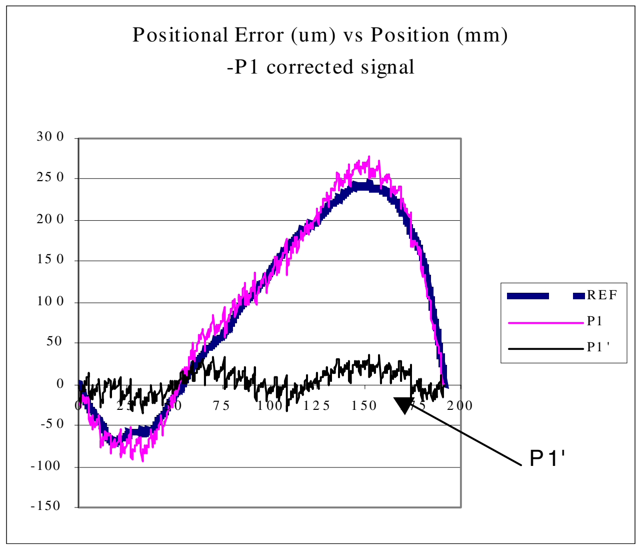

Figure 5. Positional error of P1 relative to REF.

For the corrected P1 sample, P1', a periodic disturbance, approximately 10-20 um at 80 mm period, has now come into view. This variation was previously buried under the scanner error. For printer P2, P2 yields a more accurate estimation of the low frequency error as a function of position. The next step is to evaluate this correction in frequency space.

The FFT of the corrected positional error of the REF sample is shown in Figure 7.

The high quality REF image has a very clean FFT with low noise floor ~0.04 um. Note the spectrum displays an error of 0.66 um at 0.20 cyc/mm. Since both scanners agree, this error is assumed part of the image. Also, the test scanner and HQ scanners have similar capabilities within 0.2 cyc/mm<freq <2.5cyc/mm frequency range.

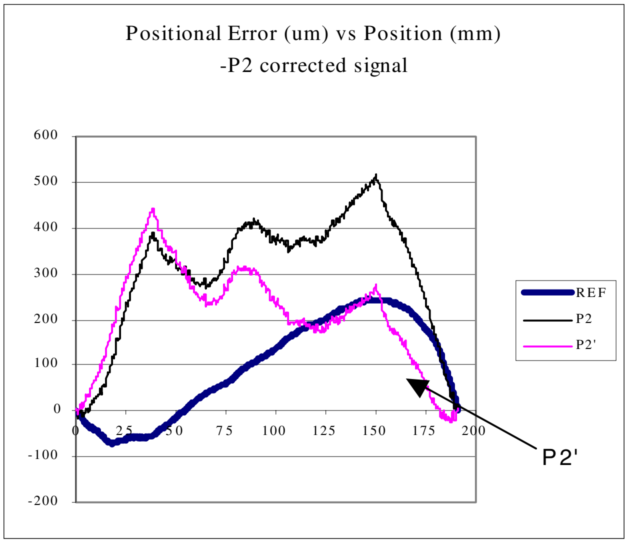

Figure 6. Positional error of P2 before and after correction

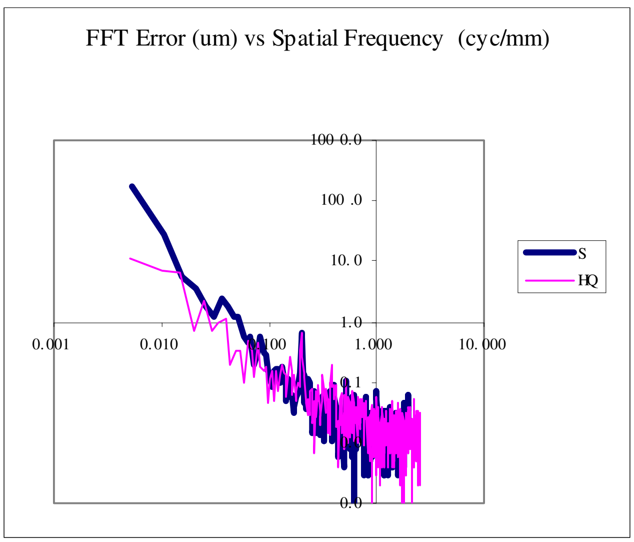

Figure 7. Spectral results for REF image measured on test scanner (S) and High Quality Scanner (HQ).

Figures 8 and 9 display P1 and P2 spectral results. As expected, the correction improves P1 low frequency positional error estimate. The P2 sample shows little difference in signal viewed on log-log scale. To aid in observing the low frequency difference, the plot is generated without the log-log scale, and displayed in **Figure 10**. It is now apparent that there is a 115 um amplitude reduction at .005 cyc/mm. P1 has excessive motion quality errors, 5.3 um @ 0.183 cyc/mm and harmonics thereof. The P2 sample has a significant disturbance of 3.2 um @ 0.408 cyc/mm.

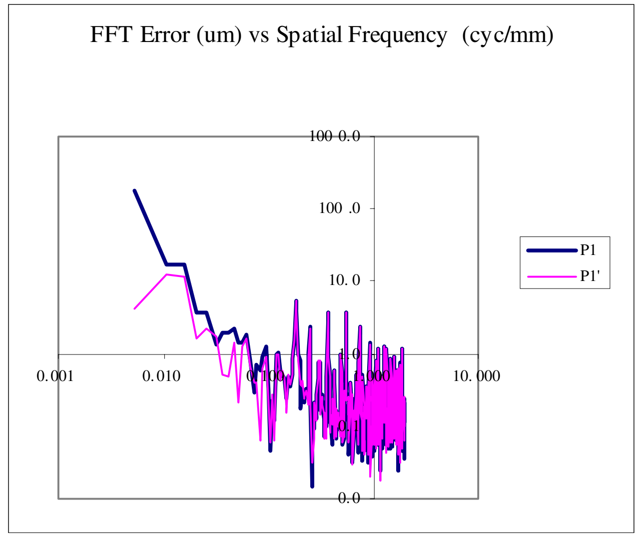

Figure 8. Spectral results for P1 and corrected P1'.

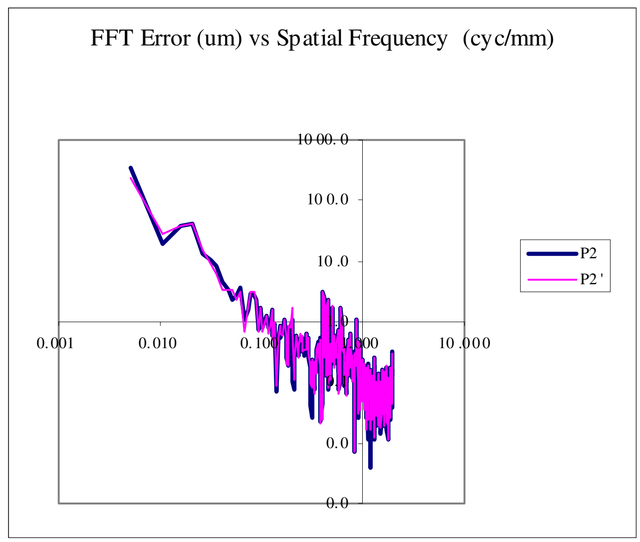

Figure 9. Spectral results for P2 and corrected P2'.

Conclusion

It was demonstrated that use of reference target is a useful technique for removing the error of the measurement device. In one case, the actual printer low frequency signal was buried in the measurement error signal. In the second case, the printer error signal and measurement system error signal were of similar frequency. Removal of the measurement system error results in a corrected estimation of the actual printer error. This technique has no effect on motion quality errors at higher frequencies.

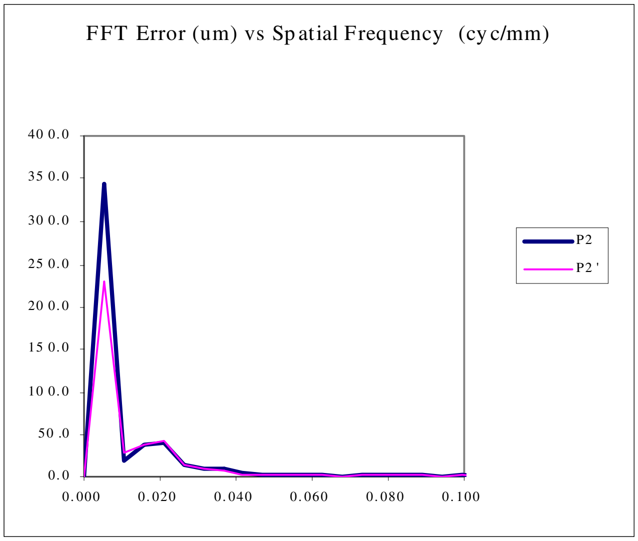

Figure 10. P2 spectral results on linear scale.

References

1. D. Rene Rasmussen, Bimal Mishra, Michael Mongeon. Using Drum and Flatbed scanners for color image quality measurements. Proc. IS&T's 2000 PICS, Portland, Oregon.
2. J. Grice and J.P. Allebach. Print quality assessment with a virtual microdensitometer, IS&T's 50th Annual Conf., 1997.

Biography

Michael Mongeon received his B.S. degrees in Mathematics and Mechanical Engineering in 1985 from University of Buffalo and MS degree in Imaging Science from Rochester Institute of Technology in 1994. Since 1986, he has worked at Xerox Corporation in Webster, NY, currently in the Wilson Center for Research and Technology. He has experience in color science, image quality, machine control software, xerographic systems integration, and process controls.