Xerox Nuvera Technology for Image Quality

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Abstract

Image flow through a digital copier involves a sequence of transformations, from the document original, to a scanned numerical representation, to a processed bitmap, to an exposure map, to a developed, then transferred, and then fused image. Technologies and architecture need to be selected to optimize copy quality, but there are many constraints, such as cost, reliability and productivity, that enter into the selection decision. In this paper we describe the rationale and benefits of the architecture and technologies behind the Xerox Nuvera Production Printing System and Xerox FreeFlow Scanner 665 and image processor. Nuvera print quality is superb due to its xerographic design; however, in this paper we focus on copy quality and the interplay between xerographic and copier image processing design. The key enablers to outstanding copy quality are the 600 spi scan resolution, segmentation and auto-windowing image processing, and a xerographic module that produces high resolution, consistent, uniform, and low-noise images. The system reflects a technology evolution in which different image processing rendering techniques are applied uniquely to each object within a single page so as to take full advantage of the superior xerographic engine.

Nuvera Xerographic Design

The key attributes which define the image quality of a xerographic engine are its *dot resolution* and *dot consistency*. In a digital system, lines, halftones and solids are all composed of dots, and unintended dot size variation leads to the majority of image quality defects, such as halftone graininess and mottle, line raggedness, and streaks and bands.

Dot Resolution

The key xerographic technology behind Nuvera's dot resolution is Hybrid Jumping Development (HJD). With this development technology, the system can reliably reproduce single pixel dots. A HJD developer housing consists of a two-component developer sump, a magnetic brush, and two donor rolls adjacent to the photoreceptor, as indicated in Figure 1. An AC biased field applied to the donor rolls causes the toner to jump from donor rolls to photoreceptor, resulting in non-contact development. The toner particles are first tribo-electrically charged by mixing and pick-up augers that cause the toner to rub against magnetic carrier particles. The toner and carrier are then magnetically attracted to the magnetic roll, forming a magnetic brush that develops a uniform layer of toner particles on the donor rolls. High AC electric fields between the donor rolls and the photoreceptor alternately attract and repel the charged toner particles, causing them to jump off the donor roll surfaces. The toner particles are then developed onto the photoreceptor under the influence of the electric field from the latent image. The non-contact nature of the development system results in excellent line and dot fidelity, and the two donor roll design, one turning with the photoreceptor, the other against, creates uniform solid areas.

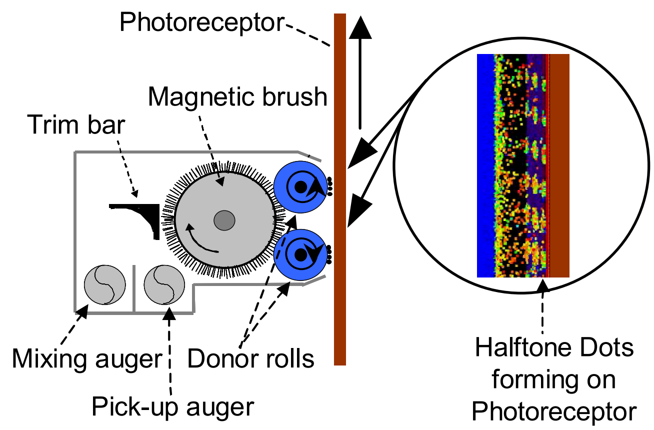

Figure 1. High Resolution Hybrid Jumping Development

Consistent Dot Size

Very subtle variations in dot size give rise to image quality defects. If you investigate a grainy halftone with an eye loupe you might wonder where the defect went! But it is still there and its origin lies in very subtle variations in dot size. Likewise, a dark streak through a halftone is nothing more than a very small increase in dot size in the area of the streak. Control dot size, and you control most of image quality!

Boiling down much of image quality to controlling dot size makes the task appear simple. But the broad objective of a xerographic product is to have consistent dot size (1) from machine to machine, (2) from page to page, and (3) within a page. These categories represent three different types of challenges which are addressed by making dot size insensitive to (1) machine to machine hardware variation, (2) temporal variation, and (3) within page spatial variation.

Hardware Variation and Xerographic Setup Routines

Hardware variation from one machine to the next can result in image quality variation. For example, image quality is sensitive to donor to photoreceptor spacing, photo-induced discharge curve (PIDC), and environmental factors such as humidity and temperature. Software based, automatic xerographic setup routines are used to compensate for hardware variation. Variation in donor to photoreceptor spacing is compensated by a routine which adjusts donor roll AC so that the critical parameter, the AC field between donor rolls and photoreceptor is constant, even though the gap may vary slightly. Likewise, a TC (toner concentration) setup routine is used to adjust TC so that Tribo (charge/mass) is maintained across all environmental zones. Finally, in order to accommodate different photoreceptor discharge curves, an electrostatic volt meter is used to measure belt voltage across a range of laser exposure levels, thus generating PIDC data which is then fit with a model (see figure 2) that is constantly utilized during printing.

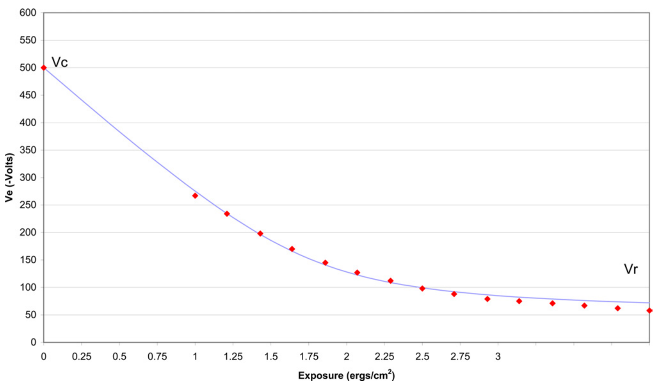

Figure 2. Machine generated PIDC data and model

Temporal Variation and Process Control

Nuvera achieves excellent temporal, page to page, control of dots through a sophisticated TRC control algorithm. Three process control halftone patches are placed in the photoreceptor inter-document zone: A highlight patch, a midtone patch, and a shadow patch. Process control actuators, such as charge and exposure, are used to simultaneously control the reflectance of the three patches. All patches are important and together they control the Tone Reproduction Curve (TRC) of the system. Their importance is further amplified because the highlight patch reflectance correlates with fine detail, the midtone patch with text density and width, and the shadow patch with solid area density. Different weightings are placed on the three patches so that greater emphasis, for example, can be placed on controlling solid density. During xerographic setup, a model is developed that relates variations in patch reflectance with variation in the control system's actuators. Then, during the printing process this model (the matrix coefficients in figure 3) is constantly used to determine how much actuator adjustment is needed to keep the three patch reflectances on target.

$$\begin{bmatrix} \Delta Charge \\ \Delta Exposure \\ \Delta HJD\_AC \\ \Delta HJD\_DC \end{bmatrix} = \begin{bmatrix} \theta_{11}\theta_{12}\theta_{13} \\ \theta_{21}\theta_{22}\theta_{23} \\ \theta_{31}\theta_{32}\theta_{33} \\ \theta_{41}\theta_{42}\theta_{43} \end{bmatrix} \begin{bmatrix} \Delta RR1\_HighLightError \\ \Delta RR2\_MidToneError \\ \Delta RR3\_ShawdowError \end{bmatrix}$$

Figure 3. Model Based TRC Control

Spatial (Within Page) Variation and Intelligent Design

Because process control only monitors small patches on the photoreceptor, additional measures are needed to maintain dot size consistency throughout the page. Small variations in photoreceptor charge lead to dot size variation. Nuvera's charging system is a split grid scorotron, where the first grid-pin combination charges the photoreceptor to near target, and the second grid-pin combination uniformly levels the charge to target. In addition, the charge device, as well as all corotron devices in the system (transfer, detack, pre-transfer and detack), have wire or pin cleaning devices that automatically run at fixed intervals in order to remove any debris that can cause dot size variation.

Finally, Nuvera uses a Teflon Over Silicone (TOS) fuser roll which offers more micro-compliance than a hard roll fuser. Without micro-compliance, fusers are notorious for causing dot size variation that is seen as hafltone graininess and solid area gloss mottle. With a silicone layer below the outer-Teflon layer, the fuser roll is able to partially comply to paper topology which makes the system's dots less sensitive to paper surface roughness.

Nuvera: A Synergistic Balance

Even the most robust xerographic systems will exhibit some level of unintended dot size variation. But intelligent image processing can make the overall system more robust by using rendering techniques that take advantage of xerographic strengths while avoiding stress bitmaps that create issues for the best xerographic engines.

The most cost effective systems are a balance of components: A balance in quality, and a synergism that enables each component's strengths to be fully leveraged in the final product delivered to the end user; in this case a high quality print. The Nuvera engine's superior imaging capability raises the bar for the larger system, demanding a commensurate improvement in document image processing to enable the engine's full potential to be reflected in each print. Interestingly, some of the same improvements in image processing which make a more pleasing print also desensitize the final output image to the residual variations in the already stabilized Xerographic imaging process.

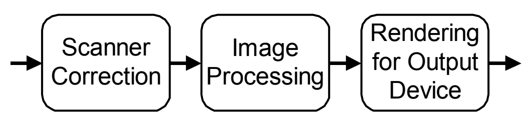

Figure 4. One-pass with fixed processing

Nuvera Document Image Processing

To understand the technology which is incorporated into the FreeFlow Scanner 665, it is helpful to understand the challenges of rendering gray images into a bi-level form for imaging on a Xerographic printer, as well as the progression of sophistication in image processing. Figure 4 depicts the least sophisticated system, one in which the processing applied is independent of the document image. The processing is predetermined by the user by selecting an operating mode which in essence identifies the document type, for example "Text", "Pictorial / Halftone", "Pictorial / Contone", "Mixed.". Figure 5 shows the subjective results of applying a variety of processing and rendering techniques to these three image types *(The nature of the subject precludes accurate reproduction in these proceedings. Actual prints will be available at this presentation).*

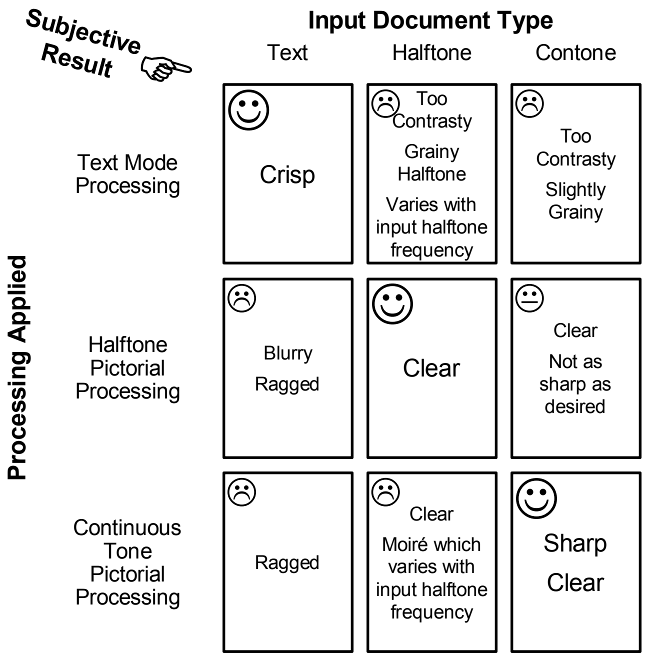

Figure 5. Document type vs. processing mode.

As you can see, no one processing approach performs optimally on all image types, although Error Diffusion is an interesting and very common compromise. Despite the obvious failure modes, fixed processing is offered on the user interface of all systems, allowing the user to force processing to be optimized for a single image type.

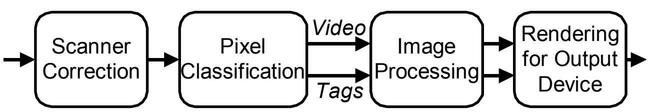

Figure 6. One-pass with pixel level analysis and classification (aka auto segmentation)

Many real-world documents contain multiple image types. Most documents have text, but many also have halftoned or contone pictorials, and some have both. Clearly no single choice of processing will perform optimally on these documents. Figure 6 depicts a system where the video in the immediate vicinity of each pixel is analyzed and the pixel is classified as to probable image type. This is a dramatic improvement, enabling more appropriate processing to be applied on a pixel by pixel basis.

The classification, image processing, and rendering algorithms, as well as the idiosyncrasies of the Xerographic process, all interact, and they must all interact synergistically. However, single pass classification systems are not completely reliable, and difficult image features are often misclassified resulting in inappropriate processing being applied. To further confound the situation, many times features within an area of one image type are in fact identical to those which in other contexts would correctly be classified as another image type. As a result, the image processing and rendering techniques in a system utilizing single pass pixel classification must be designed to perform gracefully in the presence of erroneous decisions. Enhancement filters cannot enhance as much as you would like, halftone removal filters must err on the side of removing a little more to avoid moiré, tone reproduction curves and rendering techniques must be chosen with the realization that they will at times be misapplied.

Obviously the frequency or relative number of misclassified pixels is important, but just as important, perhaps even more important, is the structure of the misclassifications since the misclassifications will lead to inappropriate processing and rendering. If the spatial distribution of this inappropriate processing is structured, this will be manifested as objectionable artifacts on the final output print.

All this said, a muted selection of appropriate processing is far superior to inappropriate processing! The net result is evident in the quality of prints from Xerox products across a wide variety of document types. Xerox digital imaging systems dating back to the original Docutech have incorporated evolving generations of pixel level segmentation to guide the image processing.

Auto-Windowing
Unleashing the Full Potential

What is required is an accurate, reliable image-type classification of large areas of the document. This would enable aggressive application of optimal processing with confidence, ensuring the best possible reproduction of every portion of the document. This also frees the system designer to choose the rendering to be synergistic with other portions of the system. Specifically, they are free to choose a rendering technique which avoids very small dots or isolated pixels, thereby reducing sensitivity of the overall system to process variations.

Figure 7 depicts the document image processing system embedded within the Xerox FreeFlow Scanner 665 and Image Processor. This system identifies pictorial windows, and tags the pixels within those windows so that they can be processed downstream as desired with confidence. The tags of pixels outside of windows are not modified.

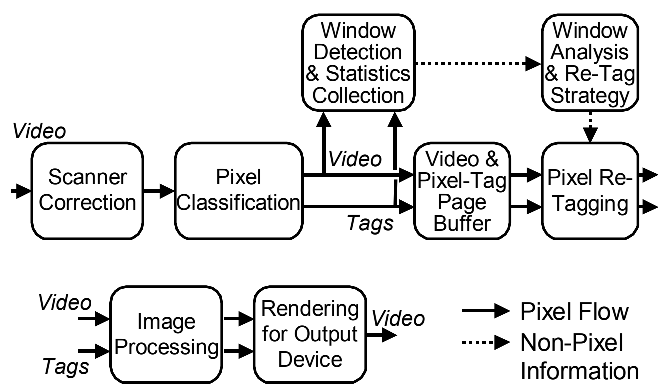

Figure 7. Two-pass with window level analysis and classification (aka auto windowing)

This is a two-pass system, electronically pipelined so as to require only one physical scan of the document and to provide full productivity. The first pass through the image performs pixel classification, detects windows, and collects statistics. As this occurs, the image and tag streams flow into a page buffer. The statistics gathered are analyzed and the Re-Tagging block is programmed prior to beginning the second pass. During the second pass the tag stream is modified by the Re-Tagging block. Downstream processing and rendering is performed much as in a single pass system, with the exception that more optimal processing can be specified for each image type as a result of the confidence provided by the window level analysis.

Figure 8 displays some of the interesting internal data streams so as to make the internal functioning of the Auto-Windowing system visible. Although they contain no video, the image is visible in the first pass Pixel Classification Tags. A window mask is developed based on the detected windows and gathered statistics, and the pixel tags modified in the window areas of the final processing tags. Pixels not associated with a window are not conceptually changed, although they are modified in pixel-oriented ways.

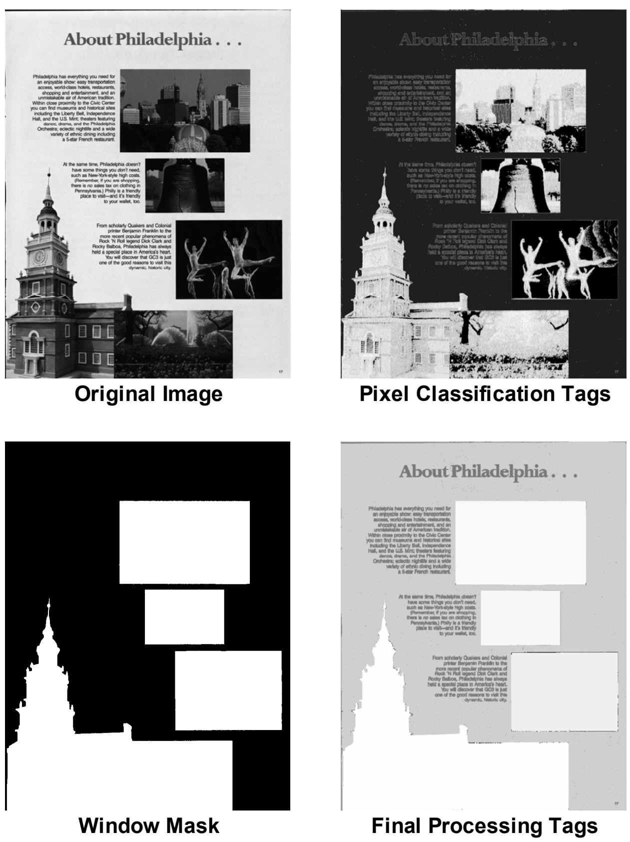

Figure 8. Window detection and tag processing

Auto-Windowing as a walk-up mode provides the best of all worlds: The quality that could be achieved through use of the specific mode controls on documents of a single image type, for example a full page of text, a full page photograph, or a full page halftone picture, can now be achieved simultaneously on each part of a mixed document. While the user still has the option to force a specific mode, there is much less need. In the rare event that Auto-Windowing does not have high confidence in the window statistics, it falls back to the robust single pass pixel classification based processing by simply not detecting any windows.

Conclusion

The net result is that the Xerox FreeFlow Scanner 665 and Image Processor teamed with the Xerox Nuvera Production Printing System delivers unprecedented reprographic quality. Whereas previous products have delivered better quality with each successive generation, this system delivers a quantum leap. A survey of customers has shown that this new technology scored the highest on a five point scale for overall image quality. This level of quality was unachievable by any other competitive product we surveyed. This is enabled by providing a superior Xerographic engine and imager, driven by superior video resulting from an object oriented analysis of each document.

While the authors are long standing members of the team who developed this technology and brought it to market, the credit truly belongs to a great engineering organization, and to each of the many people who worked tirelessly to bring this technology to our customers.

Author Biographies

Raymond Clark is the technical focal point for incorporation of Auto-Windowing and related image processing technologies into Xerox products. He holds an MSEE and BSEE from Purdue University, and has worked as an individual contributor and as a manager. He has been involved in all aspects of scanning system design and implementation, including image processing algorithms, system control architecture, real-time software, and electronics, with a recent focus on architecture to facilitate advanced document processing

David Craig is currently a senior xerographic manager responsible for xerographic technology selection and development for Nuvera and some future products. He holds an M.S. in physics from M.I.T. as well as an M.S. in System Design and Management from M.I.T. David has worked for Xerox for 16 years and during his career has been both a manager and individual contributor in xerography as well as a leader in system image quality design.