Image Quality Criteria and the Enhancement of Digital Prints

Rodney Shaw
Hewlett Packard Research Laboratories
Palo Alto, California

Abstract

In order to design robust image-enhancement techniques for digital prints it is important to understand the fundamental image-quality criteria that provide the basis for satisfactory pictorial print reproduction. Properly established, these criteria are applicable independent of the analog or digital nature of the image, and any enhancement technique should at the least be carried out with an understanding of the before-and-after quality implications. Better still, in the ideal situation the criteria themselves can be used as an integral part of the original design tools during the construction of a systematic rather than an *ad hoc* set of image-processing techniques.

The present study illustrates the use of basic image quality metrics to construct systematic procedures for the enhancement of digital-print sharpness, and for the satisfactory rendering of images covering a wide range of brightness levels. In both cases this offers the possibility of adaptive and continuously-variable enhancement techniques which are both simple in operation and undemanding of computational resources, and some progress in these directions is reported here.

Introduction

Digital printing technologies provide an obvious advantage when compared with the traditional (analog) technologies, in that they allow accessibility to the application of sophisticated image-processing techniques for the goal of achieving of optimum 'image performance'. Such techniques have been pioneered over the past few decades within the image processing community, and cover a wide variety of performance criteria, from machine detection and recognition of complex signal-types to the visual inspection of pictorial imagery. It is well-known that the appropriate sub-set of these techniques, when properly applied, can influence most aspects of perceived pictorial image performance, from straightforward augmentation of tone reproduction to the more sophisticated requirements of sharpness filters and noise suppression techniques.

In spite of having this well-established image-processing background to draw from, the consumer digital-photography/digital print community has been somewhat slow to capitalize on this potential competitive advantage over analog imaging systems, and in the main, only *ad hoc* techniques have actually been incorporated, and on a fairly scattered basis. The reasons for this are many, and range from unfamiliarity of what has already been achieved in other imaging technologies, to more esoteric questions concerning the stage at which these techniques should reside within an end-to-end digital imaging system (including print stage).

At recent conferences in this series the author has concentrated on the task of developing absolute image quality metrics for digital printing, and has reported specifically on such scales for print sharpness and noise.[1,2] The approach taken in the development of both of these was based on a simple Fourier description of the visual process, and a spatial frequency integration of this visual function with the relevant signal and noise spectra associated with the printed image. It is the thesis of this present study that basic knowledge of these essential spatial-frequency characteristics which are associated with the perceived impression of high-quality printed images can lead to significant clues as to where and how new digital enhancement techniques may be relevant. As a preliminary we review the analytical approach to print sharpness.

Print Sharpness and Edge Enhancement

The sharpness problem in digital printing may conveniently be framed in terms of the resolution element in the printed image, and hence the ppi associated with the print. Figure 1 shows the digital sharpness scale in these terms, where a sharpness value of 8 or higher is required to match reasonable (analog) photographic print quality. This clearly indicates the problem of achieving comparative photographic levels of sharpness with digital printing technolo-

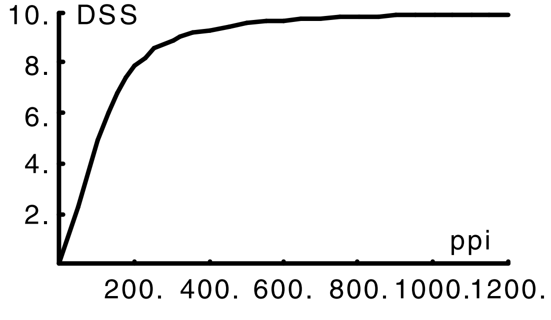

Figure 1. Digital sharpness as a function of pixels-per-inch in the digital printing device.

gies, and suggests the need for the incorporation of appropriate sharpening techniques, as well as providing a absolute measure of the effectiveness of such techniques.

The spatial frequency basis for Figure 1 is shown in Figure 2. This shows the assumed visual transfer function (VTF) associated with normal print viewing, as well as its product which is assumed to serve as a an overall surrogate for the detail spectrum of the print. The problem so stated is thus to devise sharpening techniques which increase the total area within this spectrum.

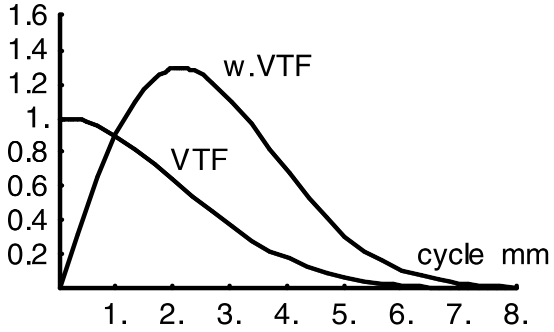

Figure 2. The visual transfer function and its frequency weighted value, assumed to represent the print detail spectrum.

In conventional photography the fundamental limits to sharpness are driven by light-scatter in the negative during image capture, and projection of the resulting spread function onto the final print. Of special interest here is the existence of so-called interlayer effects that take place during development, and which have been exploited as analog sharpness enhancers, and whether these can be matched by digital enhancement techniques in the case of digital printing .

Figure 3 shows a series of idealized edge transfer functions (ETF) based on the nature of these functions in the analog case, the lower, horizontal, curve relating of course to the un-enhanced case. If these were at our disposal in the digital case, then their influence on print sharpness could be represented by the curves of Figure 4, where the ETF curves of Figure 3 have been cascaded with the VTF/spatial-frequency product of Figure 2. Inspection of the resulting curves, referred to here as the visual detail function (VDF) shows clearly the potential sharpness gains which would accompany such enhancement techniques.

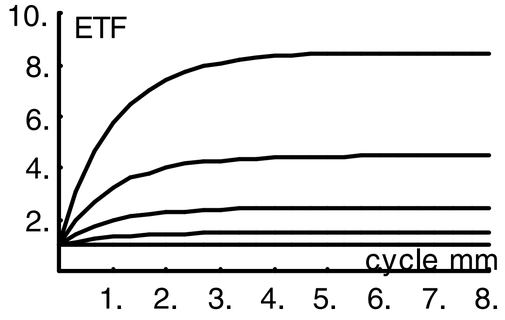

Figure 3. Idealized transfer functions associated with edge enhancement techniques.

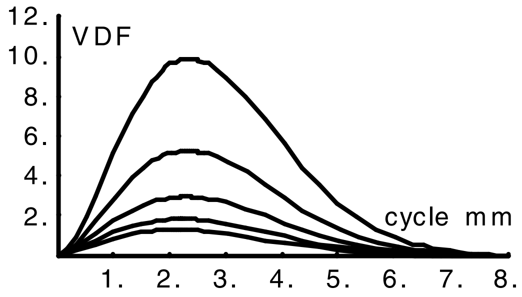

Figure 4. The visual detail functions associated with the edge transfer functions of Figure 3.

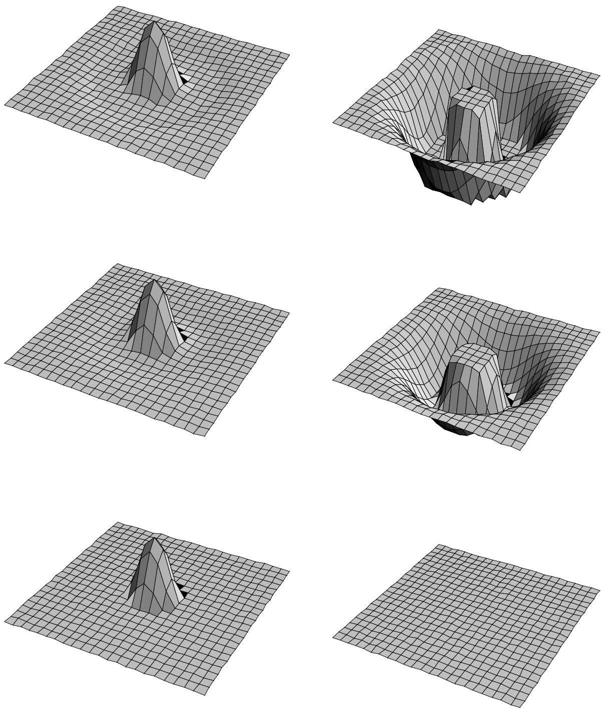

Figure 5. Digital enhancement filters (left), with enlarged version of the corresponding negative lobe shown on the right.

The nature of the series of idealized edge transfer functions of Figure 3 suggests their incorporation within a variable sharpening filter which spans the appropriate practical range of interest. To do takes careful translation in both the amplitude and spatial frequency domains, resulting in as series of filters as illustrated schematically in Figure 5. Here the variability is represented by the magnitude of the negative lobe, as shown magnified, to the right.

An example of the results of a variable edge-enhancement filter constructed along these lines is shown in Figure 6. This is an enlarged section of a digital print considered to be of satisfactory quality other than in the attribute of sharpness. Starting with the original un-enhanced version (top), the results of successive increases in the amplitude of the filter are shown below. In this particular case the picture on the scale as printed was originally judged to be outside the generally acceptable photographic range, but after enhancement was judged to be well within this range, and this was confirmed by calculation of the changes on the associated digital sharpness scale. Of course, in general the limits to which such enhancement may be made will be governed by personal preference, as well as by the inherent noise level and its own spatial spectrum, since this will also be enhanced unless other noise-suppression techniques are used in unison. However such considerations are beyond the present scope.

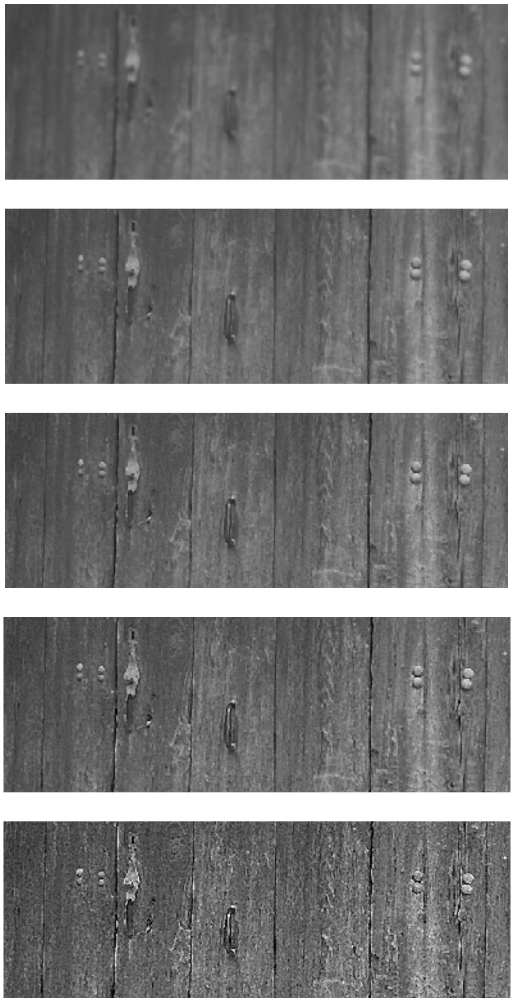

Figure 6. Enlarged section of digital print (top) and as edge - enhanced by a variable digital sharpening filter.

Print Latitude Extension: Adaptive Processing

Another common class of image-quality problem that is encountered in digital printing relates to the accommodation of scenes having a high dynamic range of brightness levels, especially so with the increasing use of digital acquisition devices with technologies capable of extended-range scene-capture. The associated problem is that in natural scenes where the preponderance of the natural print detail falls within the highlight or shadow area of the print, and when the problem cannot be rectified by global mean-level amplification techniques (ie, the classical analog approach of tone-manipulation). One useful approach to this problem follows naturally as a corollary to that used above in constructing a sharpening filter. However the problem is now more complex, and calls for an adaptive form of spatial filtering and more specifically, selective local enhancement within defined spatial frequency bands.

It has been found useful to view this problem as a two-stage spatial-filtering problem, the first involving removal of very low spatial frequencies which have little on the perception of detail, and by doing so re-mapping the extreme regions towards the intermediate brightness regions, allowing a second-stage re-stretching of the important spatial frequencies as defined by Figure 4 into the brightness regions thus vacated. In this way all the existing boundary conditions across existing edges in the image can be maintained, while, in effect, ‘making room’ for edges at the extremes which were otherwise absent or under-represented in the perceived image. In this way the enhancement of the important higher spatial frequencies more than offsets discarding the very low frequencies, thus conveying the visual impression of increased sharpening overall, as well as the obvious advantage of viewing detail in the extremes not otherwise above the visual threshold.

Figure 7 gives a pictorial example of typical results obtained by this approach. This shows a section of a digital scene wherein shadows and highlights dominate, and the main subject matter of interest contains both. Below this is an illustration of the results of conventional tone manipulation. The subject matter is now clearly visible overall, but at the expense of a washing out of the natural highlights. Finally, the result is shown of a two-stage spatial-filtering technique, that as described above, selectively suppresses low spatial frequencies and enhances higher frequencies. It is seen the detail is now reproduced in a satisfactory matter everywhere, including both shadows and highlights. Again, this was made possible by effectively filtering out very low frequencies which themselves contribute little to the perception of detail.

As in the case of the edge-enhancement filter, an attractive feature of this adaptive latitude-extension filter is its continuous nature, as illustrated in Figure 8. A common problem encountered in printing digital or analog photographs is posed by originals in which the use of flash has ‘washed-out’ the intended scene highlights, often in the form of facial features. Figure 8 shows an example where variable degrees of adaptive enhancement of the highlight details has followed conventional global tone-manipulation. This small but key element of the image may be enhanced to user preference, but not at the expense of detail in the general surrounding areas of the image. In Figure 8 the degree of enhancement has been taken beyond reasonable user choice in order to illustrate the continuity and extent of the operation made possible by the prudent choice of low-spatial-frequency band-with, starting from fundamental image-quality considerations.

Figure 7. Illustration of a section of a digital print involving strong shadows and highlights (top); as tone-manipulated (middle); and as adaptively spatial-filtered (below).

Conclusion

It has been demonstrate how the fundamental image quality attributes of printed images may be used as a basis for the design of image processing techniques for the purpose of the enhancement of desirable image features. Examples have been given in terms of a variable edge enhancement filter matched to the spatial frequency bandwidth of the print as viewed, and to the extension of perceived print latitude when otherwise detail would be lost in the shadows or the highlights. In both cases the spatial-frequency spectrum that defines the basic image quality attributes of the perceived print has been built into the enhancement procedure in a way that allows both a continuously-variable enhancement scale and the prediction of the before-and-after image quality attributes associated with the enhancement. In the latitude-extension case these important considerations lead to an technique which adapts naturally to the local properties of the image detail.

Figure 8. Illustration of various degrees of restoration for scene highlights using an adaptive enhancement filter

References

1. R. Shaw, IS&T *Procs. NIP 12,* 1996, pg 162.
2. R. Shaw, IS&T *Procs. NIP 15,* 1999, pg 446.

Biography

The author received a PhD in physics from Cambridge University. After several research and teaching positions in the UK and Europe he came to the USA in 1973, and following research appointments at Xerox and Eastman Kodak was Director of the Center for Imaging Science at RIT. He joined H-P Labs in 1994, and his current interests are in image processing and digital systems modeling. *rodshaw@hpl.hp.com*