Image Processing Opportunities in Digital Photography

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Abstract

The technologies which are the basis of digital photography offer the potential for a range of performance advantages when compared with traditional analog technologies. Some of these advantages are obvious, and are concerned with digital convenience, while others relate to overall levels of photographic performance. One particular area of potential advantage is the ready access to digital image enhancement techniques from among those that have been pioneered over the past few decades within the image processing community. These techniques, appropriately applied, can influence most aspects of photographic image performance, from straightforward augmentation of tone reproduction to the more sophisticated requirements of sharpness filters and noise suppression techniques.

Some of these opportunities are considered here, with emphasis based on the desired visual properties of the final image, and how these may be more closely approximated with the help of image enhancement techniques. It is suggested that basic knowledge of the essential spatial-frequency characteristics associated with the perceived impression of high-quality photographic images can lead to significant clues as to where and how new digital enhancement techniques may be relevant.

Introduction

In a separate contribution in these same proceedings the author has discussed the topic of ultimate photographic performance within the digital context, how such performance may be tracked against the limitations imposed by the underlying digital technologies, and how these limitations compare to those that are fundamental to traditional analog technologies[1]. This study was based on an end-to-end SNR-based model that includes significant technological drivers (hardware) on the one hand, and the most important imaging-performance criteria on the other.

Excluded from this study was the topic of present interest, namely the extent to which image enhancement techniques (software) might be applied within the end-to-end chain. The purpose of such software might be either that of straightforward visual enhancement and optimization of images already delivered in efficient manner by the system in a signal-to-noise ratio sense, or to overcome deficiencies in the system which lead to inadequacies in performance, for example limited tone reproduction, lack of sharpness or image noise above the limits acceptable for quality photographic images.

By and large the digital community has so far shown few signs of grasping the fundamental opportunities offered by image processing in any systematic manner. Most of the resources and endeavors in this field have perhaps gone towards the basic problem of creating a consistent bit-highway through to print, and to the handling of color reproduction in a standard, uniform way, for example establishing compatibility between a variety of capture, display and printing devices. In this context it is not naturally straightforward to identify the appropriate stage at which 'smart' image enhancement and optimization should take place for the benefit of the system as a whole, and within which device it might reside. Sophisticated consumers of digital photography, if dissatisfied with any aspects of the image are thus left to their own resources in the software after-market. This is a rather different situation from that of traditional photography, evolving over the decades largely as a (closed-system) negative-positive-process provider, and therefore overall photographic performance was implicitly the responsibility of the system supplier.

Since the author has indicated[1] that two primary performance challenges associated with digital photography are those stemming from the sharpness limitations associated with current pixel array sizes, and the accommodation of the potential extended-latitude image-capture capabilities of multilevel detection, this present study will summarize approaches towards the solution of these specific problems.

Image Sharpness

The sharpness problem in digital photography may be framed in terms of the relationship between the sizes of the detector array and the final print[2]. Figure 1 illustrates the sharpness outcomes for a range of detector and print sizes, (a sharpness value of 8 or higher being required for good photographic quality), and hence the difficulty of meeting this requirement with contemporary consumer systems.

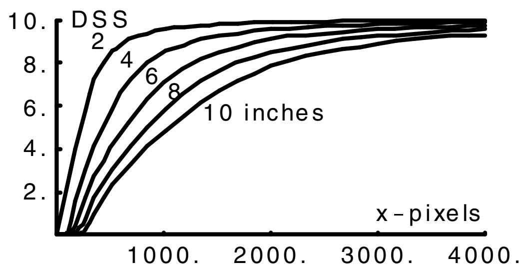

Figure 1. Digital sharpness as a function of required print size and number of detector pixels on a side.

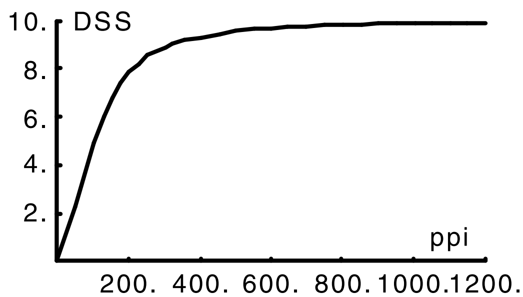

Figure 2. Digital sharpness as a function of pixels-per-inch in the digital printing device.

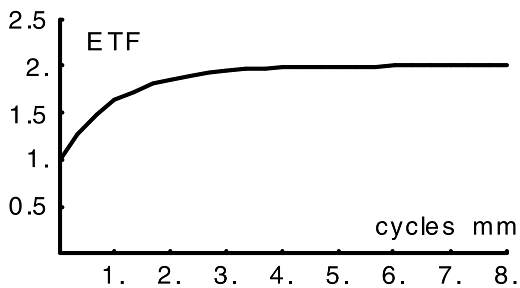

Figure 3. Enhancement transfer function associated with interlayer coupling mechanisms in silver-halide photography.

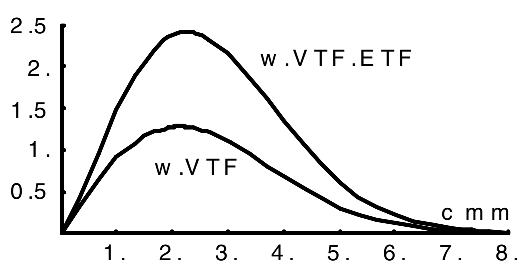

Figure 4. The image-detail spatial-frequency spectrum before and after cascading with the enhancement transfer function.

From the viewpoint of digital printing the situation is similarly problematic, as illustrated in Figure 2, recalling that to meet separate noise requirement the printer must meet stringent gray-level capabilities at this same print resolution.

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 sharpness enhancers. Figure 3 shows an idealized 'edge-enhancement' transfer function (ETF) associated with this phenomenon.

The spatial frequency scale in Figure 3 has been assumed to be that of the final print viewing conditions. When on this scale the ETF is cascaded with the product of the visual transfer function and the spatial frequency itself (the latter product considered as a surrogate for the scene detail spectrum[2]), we see in Figure 4 the dramatic increase due to the presence of the enhancement function.

The nature of this effective enhancement filter has similar spatial frequency characteristics to those found in a variety of alternate imaging technologies, standard image processing operators and observed visual phenomena. An idealized circular-symmetric spread-function based on such a spatial filter is shown in Figure 5, where the degree of 'edge-enhancement' is defined by the extent of the negative lobe. Absolute scaling of such a function to the image, and adapting the degree of edge-enhancement to the local image sharpness requisites, poses a formidable challenge, especially since the degree to which it may be applied will of course depend on practical image-noise levels.

The effect of building spread-functions of the nature in Figure 5 into a (variable) digital filter is illustrated in Figure 6, where a highly enlarged set of fine lines have been subject to increasing degrees of enhancement. In the original digital image from which these lines were taken, only the two wider lines were visible, but with an increasing amount of enhancement the whole series becomes clearly visible, and there is an overall impression of sharpening throughout the image.

Tone Enhancement

The accommodation of extended-latitude pictures made increasingly possible by the use of multilevel digital image capture technologies poses a further problem where the use of image processing algorithms may provide an acceptable solution. Such a problem is assumed to exist aside from the *a priori* optimization of the mean-level characteristics (ie, conventional tone-reproduction). Here the spatial extent of the enhancement filter, or image-processing algorithm would naturally be anticipated to much greater than those used in local adaptive sharpening discussed above, and in extreme cases might be in the form of an image-wide operator simultaneously acting on all parts of the image, with accompanying computational complexity.

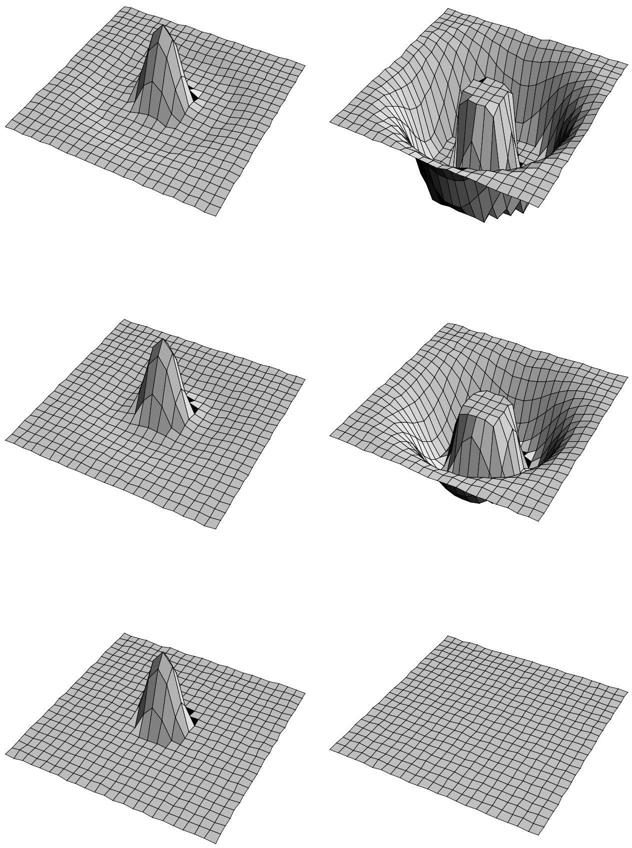

Figure 5. Digital enhancement filters (left, with enlarged version of the corresponding negative lobe shown on the right.

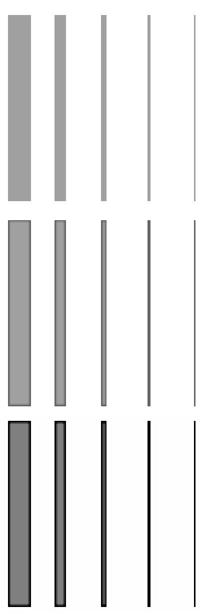

Figure 6. Enlargement of a series of fine lines showing original (top) and the effects of increasing enhancement (below).

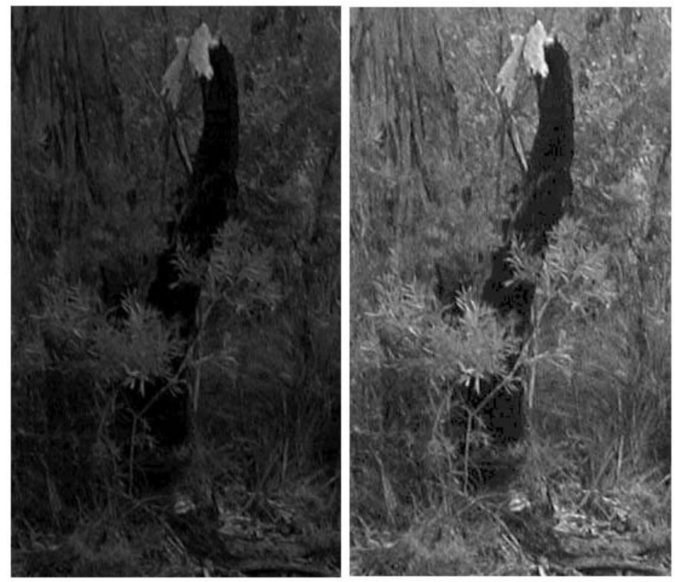

Figure 7. Enlargement (before and after) of shadow area in extended-latitude digital image.

Figure 8. Enlargement (before and after) of highlight area of extended-latitude digital image

One class of practical solutions to this extended latitude problem is based on a variation of the filters discussed above within the sharpening category. Such variations can provide simple, less computationally intense solutions to the problem, while giving up little or nothing in perceived image quality. Examples are shown in Figure 7 and 8, where enlargements of digital image segments in the shadows and highlights are shown, before and after the use of simple tone-enhancement algorithms, which make possible the simultaneous image visualization of these problematic exposure regions.

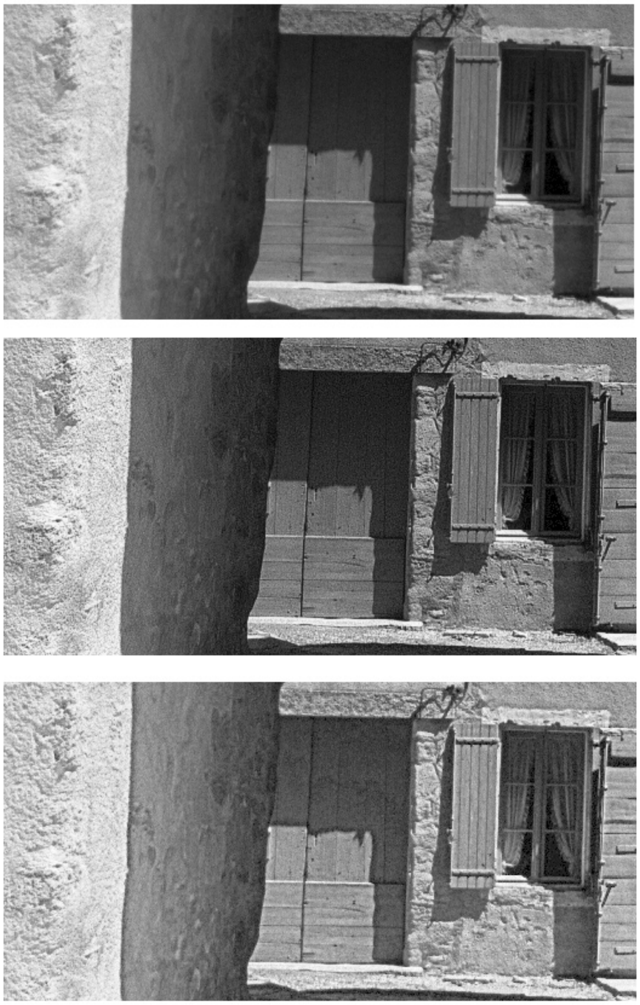

Figure 9. Original (above) and as sharpened (middle) and tone-enhanced (below).

In the practical case limiting detail may be enhanced by a combination of these (high-spatial-frequency and low-spatial-frequency approaches, and Figure 9 shows an example of an enlarged image detail.

Conclusions

In order to overcome current performance limitations and to open up new areas of photographic dynamic response within the digital context, increasing appeal will be necessary to sophisticated image processing techniques, examples of which have been discussed here.

References

1. R. Shaw, (in these proceedings)
2. R. Shaw, p71 Procs IS&T PICS Conf 2000.

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.
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