Reprinted from SPIE Vol. 1092--Medical Imaging III: Image Processing

QUANTITATIVE STUDY OF DECONVOLUTION AND DISPLAY MAPPINGS FOR LONG-TAILED POINT-SPREAD FUNCTIONS

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ABSTRACT

An important goal in medical imaging is to increase the accuracy of visual detection of small abnormal regions. The presence of scatter in the image degrades spatial resolution by introducing long tails to the point-spread function. We show in this paper that linear deconvolution can be used to improve the performance of the human observer in the two-hypothesis detection task. Also, we investigate the effect that linear grey-scale mappings have on the human observer performance. We demonstrate that they help the human observer in the detection task and can be used sequentially with deconvolution to yield a better performance.

1. INTRODUCTION

In most forms of medical imaging, diagnostic information is acquired through visual observation of the images. It is thus natural to assess the performance of an imaging device by studying the ability of human observers to perform specific detection tasks. The task of interest in this paper is a simple two-hypothesis detection task where the human observer is asked to detect a low-contrast disc signal in a quasi-uniform background. Through repeated trials, a receiver-operating curve (ROC) can be plotted and the index of detectability d'_a derived.[1,2] An absolute scale such as the detectability of the ideal (or a pseudo-ideal) observer performing the same task is generally used as a standard of comparison.[3]

The study of imaging systems that can be characterized by a long-tailed point-spread function (PSF), for example, systems limited by scattered radiation, are our interest because they address the question of how to assess image quality in a meaningful way for the human observer. In a preliminary study that addressed this question, we showed that the performance of the human observer correlates better with the no-low-frequency (nlf) ideal observer than with the ideal observer.[4] By nlf ideal-observer we mean the ideal observer having the low-frequency component, corresponding to the signal convolved with the tail of the PSF, suppressed. In the studies reported here, we choose the detectability index d'(nlf) as the absolute scale of comparison.

Moreover, long-tailed PSFs are of significant general interest in image processing and, more specifically, deconvolution. We have shown in our previous study, that deconvolution does help the human observer in the detection task. One posssible explanation for this result is that the operation of deconvolution reduces the dynamic range of the images, thus allowing them to be displayed at higher contrast.[5] This important point, is stated quite generally by Wagner as, "..imaging is essentially a two stage process.... The first or detection stage is assessed in terms of an ideal observer, task dependent signal-to-noise ratio (SNR), which is simply a measure of the statistical quality of the raw, i.e., unprocessed, detected data in the light of the task required of the observer. The second or display stage is evaluated with respect to the coupling of this information to the human observer, a phenomenon assessed in terms of observer or display/observer efficiency."[6]

For the task at hand, we propose in this paper to quantify the effect of linear grey-level mapping on the unprocessed and processed images. We investigate the contribution of deconvolution to contrast enhancement apart from the contribution of linear mapping.

2. OBSERVER STUDIES

The imaging process is depicted in Figure 1. The object consists of a low-contrast disc signal superimposed on a smoothly varying background. This object simulates, for example, the presence of a tumor in a quasi-uniform region of interest. The PSF of the image-forming element is characterized by a sharply peaked core with an extended tail that is typical of systems limited by scattering processes. Uncorrelated Poisson noise is then introduced in the image before display to acccount for fluctuations in the photon detection process (see Figure 1a). To study the effect of deconvolution, these images are convolved with a sharpening filter derived using Fourier theory (see Figure 1b).[7]

The parameters chosen for the experiments (i.e., signal contrast, widths of the PSF's tails...) are the same as those described in our previous work.[4] During the experiments, the contrast and brightness of the CRT monitor were kept constant and checked systematically. The experimental data presented in this paper are the average responses over six observers. They were asked to rate their certainty of detection on a six-point rating scale.

First, we studied the effect of deconvolution on the noisy images by displaying the unprocessed images to the observer without grey-level manipulation. As for the processed images, their range of grey-level values fell outside of the 256 grey-levels available. Thus they were scaled--without any stretch--before display. Also of importance to the study are display effects introduced to the images due to the CRT monitor (i.e., linearity of the display, scattering in the phosphor).[8] These display mappings are important since they relate the ideal to the human observer. These issues are under study and will not be presented in this paper.

Second, we studied the effect of a linear stretch on the images by mapping their values over 256 grey-levels. Also, a more extensive stretch can be achieved by applying a grey-level window to the image before stretch. This windowing technique, commonly used in image processing for contrast enhancement, was applied on the unprocessed images and included as a supplementary study. The grey-level window used in the study allowed us to keep half of the full range of the actual grey-level values in the images, without altering the signal.

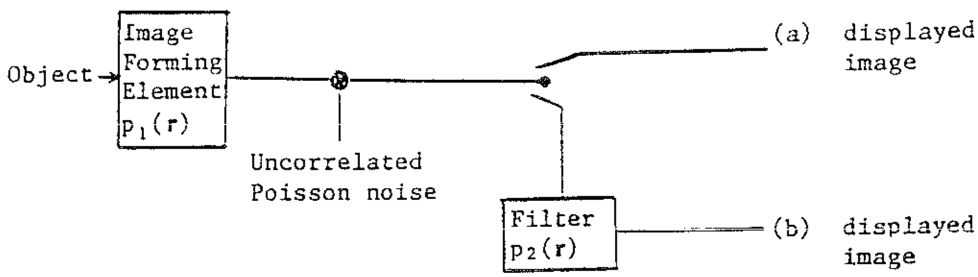

Fig. 1. (a) Basic scheme of a nuclear-medicine imaging system. The object is convolved first with $p_1(r)$. Uncorrelated Poisson noise is then introduced to account for fluctuations in the detection process. (b) The noisy images are convolved with the deconvolution filter $p_2(r)$ before display.

3. RESULTS

The results of these studies are presented in Figures 2 to 4 where we plot the detectabilities calculated from the ROC analysis versus the detectabilities predicted from the nlf ideal observer. Figure 2 shows the improvement due to deconvolution on the noisy images. The increase in slope from 0.49 to 0.57 reflects the effect of deconvolution apart from contrast stretching. The images were then stretched over the full range of available grey-levels. The results are presented in Figure 3. They show an increase in slope for both processed (from 0.49 to 0.57) and unprocessed images (from 0.57 to 0.65). An additional upward shift in intercept results for the processed images after stretch. The overlap of the two lines tells us that by performing either deconvolution or linear stretch on the images, the performance is increased by the same amount. However, if we now apply sequentially deconvolution and stretch, the performance is greatly improved. From these results, we believe that deconvolution leads to the best performance for the observer/display system and that deconvolution does help the human observer to improve his ability of detection. Questions still remain however. Will further stretch on the images improve performance, and can we well define the effects of display?

We answer the first question by looking at the effect of grey-level windowing. The results are presented in Figure 4. They show that the performance achieved with this windowing technique is essentially equivalent to the performance achieved when deconvolution and stretch were applied sequentially. These results may be interpreted as follows. Let us consider Figure 5, which displays some examples of images containing a signal. The top left image is an example of an image before deconvolution and stretch, while the top right image is the same image after deconvolution. The bottom right image represents the effect of deconvolution and stretch using 256 grey-levels. Finally, the bottom left image illustrates the grey-level windowing technique on the unprocessed image. While, by performing contrast enhancement, the contrast of both the signal and the noise is increased, we expect the SNR to remain constant. Acccording to the theory of constant internal noise, this is the case unless the contrast of the signal to the background before stretch is below the contrast threshold of the eye.[9,10] We should note on Figure 5 that the noise does indeed become more visible after both deconvolution/stretch and windowing. For Gaussian disc signals and backgrounds, it is not clear how to define the contrast of the signal on the background. Some photometric measurements are under process to try to solve this problem. Then, curves of contrast threshold versus the reciprocal of the visual angle subtended at the eye --for Gaussians or fuzzy shapes--will be used, and we hope to be able to confirm our hypothesis that the human observer was limited by constant internal noise when no stretch was performed on the images.[11,12,13]

4. CONCLUSION

We showed that linear deconvolution helps the human observer extract more information from the observed images but leads only to a suboptimal solution. When images were stretched over 256 grey levels the performance of the human observer was greatly improved. Thus, deconvolution/stretch is the best solution for the observer/display system. We believe that the increase in SNR due to linear stretch can be explained with the theory of constant internal noise. To be able to justify this hypothesis, we must define the contrast of the signal on the background for the case of Gaussian distributions . Then, we must use a curve of contrast thresholds of the eye versus the reciprocal of the subtended visual angle for Gaussian discs. Those issues are still to be investigated. We also showed in this paper that, for our simple task, grey-level windowing competes with deconvolution/stretch, but it remains to be seeen if this is also the case for non-uniform backgrounds. In the future, we shall be looking at display effects, such as the effects of non-linearity of the CRT monitor and scattering in the phosphor, on the visual response of the human and ideal observer to investigate futher aspects of the coupling of information to the human observer.

5. ACKNOWLEDGMENTS

The authors would like to thank Arthur Burgess and Robert Wagner for some very helpful discussions. We would like also to thank all the people who participated in the observer studies for their patience, enthusiasm and strong cooperation. This work was supported by the National Cancer Institute through Grant No. P01 CA 23417.

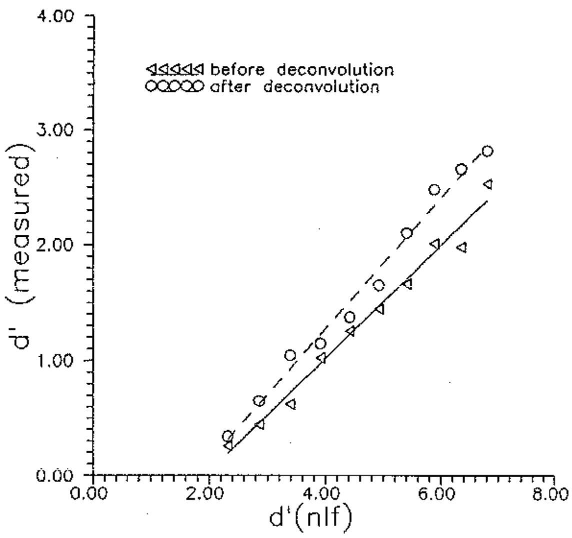

Figure 2. Detectabilities calculated from experimental data d'(measured) versus detectabilities predicted by the no-low frequency ideal observer d'(nlf).

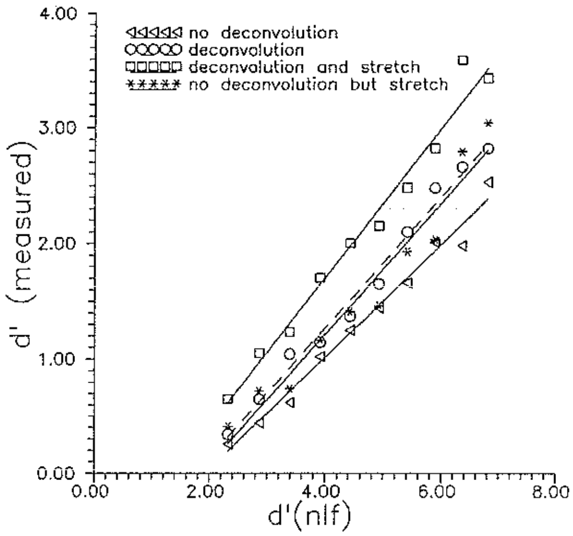

Figure 3. Study of deconvolution and stretch.

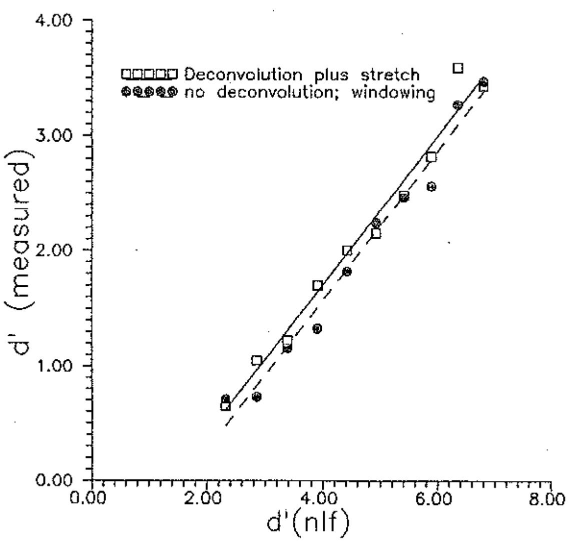

Figure 4. Effect of windowing on the unfiltered images. Comparison with the operation of deconvolution plus stretch.

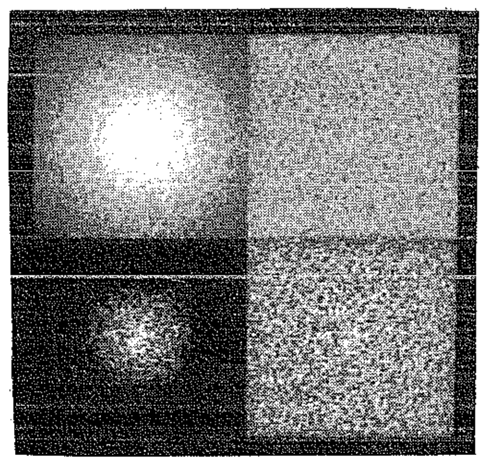

Figure 5. An example of four simulated images with: (a) top left, unprocessed (b) top right, processed.(c) bottom right, processed plus stretch. (d) bottom left, windowing.

6. REFERENCES

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