OPTIMAL INFORMATION RETRIEVAL FROM COMPLEX LOW FREQUENCY BACKGROUNDS IN MEDICAL IMAGES

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ABSTRACT

We studied the application of image processing techniques to digital/filmless radiographs. The planar x-ray images were generated using high resolution photostimulable phosphor plate technology. We optimized the images' information content by repeated application of morphological closing and opening operations followed by a convolution and a subtraction. We have been able to dramatically improve, though heuristically, a broad variety of medical images by offline, interactive application of similar processing methods. We suggest criteria which may form the basis for image processing decisions such as structuring element size and the suitability of probability quantization.

INTRODUCTION

Efforts to automate image enhancement routines for application to routine diagnostic medical images are often frustrated by a poor reception by clinical radiologists. We need to find image processing techniques which can be usefully applied to a significant number of the huge variety of medical images produced daily.

It may remain unrealistic to propose to automate or standardize image processing methods over all modalities and all anatomical structures. However it might be possible, in a context-dependent fashion, to rationally delimit the array of available image processing tools.

Many kinds of images may be optimized using similar processing algorithms. To date, we have achieved this interactively by modification of the results at each stage. We present observations regarding how the original data histograms, the spatial frequencies of objects of interest, and the spatial frequencies of irrelevant structures might be used to guide the selection of processing parameters. Establishing automatable analytical means to determine sensitive processing parameters would represent an important step in bringing digital image processing into broader utilization.

BACKGROUND

The output of morphological operations retains spatial frequencies corresponding to feature dimensions larger than the structuring element's dimensions [1]. Closing and opening are analogous to the ideal bandpass of linear signal filtering. They share the property that repeated application affects no further change in the data.

Many non-discriminating low-pass filtering methods have proven acceptable in removing high frequency image noise on-line. In diagnostic images, very low frequency "noise" often occurs such as the tapered brightness of surface-coil MR images or the mere presence of thick attenuating objects in the image. However, the simple convolution unsharp masking approach recently accompanying the arrival of computed filmless radiography has been one of the few attempts to remove irrelevant low frequency image features. These routines are not, at present, very flexible, and in their fixed-parameter implementations do not invariably provide the best image quality. In some cases the edge-enhanced appearance of these images may annoy the clinician.

Closings and openings using appropriate structuring elements produce a background image which may then be subtracted from the original to produce a result in which the very frequencies eliminated by morphology are emphasized.

METHOD

We extended greyscale morphological background normalization techniques to digital radiographs produced with high resolution photostimulable phosphor plate technology [2]. We had previously demonstrated the success of such methods applied to surface-coil MR images of the lumbar spine [3] which suffered from an uneven background caused by the radial sensitivity function of the surface coil.

The images in this study suffer varying degrees of exposure latitude problems. The intermediate and higher frequency information-rich portion of the signal is riding on the low frequency function corresponding to the slowly varying object section thickness. Detail is lost at both brightness extremes because the grey levels oscillate around local means above or below the range in which the contrast resolution of the visual system is maximal.

We have tailored a morphological filter sequence to provide a suitable background for weighted subtraction from a wide variety of medical images. We perform successive closings ($\bullet$) and openings ($\circ$) using square, origin-centered structuring elements of increasing size followed by blurring ($*$). The final image I becomes: $I = I_0 - ß\{[(I_0 \bullet q) \circ k]_m * b_n\}$, where $[(I_0 \bullet q) \circ k]_m$ represents the series of m successive closings and openings with structuring elements q and k. This result is then convolved with square kernel b n times, multiplied by weighting factor ß ($0.3 < ß < 1.0$), and subtracted from the original image.

Tailoring the sequence consists of choosing the dimensions of q, k and b, determining the numbers of applications m and n, and choosing the weighting factor ß. The possible advantage of performing a probability quantization on the image grey levels either before (on I_0) or after the standard sequence was also investigated.

RESULTS AND DISCUSSION

Original and processed images of the shoulder and ankle are shown in Figures 1 and 2, respectively. We used m=n=2 for both images. For the first iteration $|q|=|k|=3$ and for the second $|q|=|k|=7$, where $|\ |$ denotes size in pixels. For these images 7x7 and 11x11 convolution kernels proved optimal. For approximate scale, the dark lines in both images correspond to dimensions between 5 and 10.

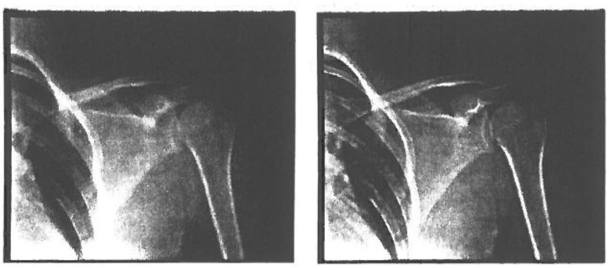

Figure 1: Shows the original shoulder image (left) and the processed result (right).

Conceptually, the background to be subtracted should not contain any desirable image detail. This would indicate that structuring elements q and k might be chosen larger than the largest objects of interest. We find, to also satisfy the requirement that bright areas of the background image should not extend too far beyond the margins of their counterparts in the original, that the largest structuring element used should actually be slightly smaller than the largest objects of interest.

The choice of ß is critical in determining subtle feature conspicuity in the final image: If the original image is marginally acceptable, as the shoulder image is, ß's ≈0.5 produce the best result while for images with severely underexposed regions, as in the original ankle image, ß's ≈0.75 work better. Small fluctuations in the value chosen for ß have profound effects on final image detail, in contrast to the forgiving nature of the consequences of structuring element size choice.

A greylevel probability quantization (GPQ) of the original data invariably degrades the results. Whether the final image benefits from GPQ may be largely a matter of preference. The ankle of Figure 2 was so processed after subtracting the background. Quantization affords most benefit when the original image was improperly exposed: For better original image data, GPQ often produces the obnoxiously high-contrast appearance typical of automatic edge enhancement routines.

It may be possible to choose ß based on some parameter of the initial data histogram. We postulate that integrated area or skewness may be appropriate parameters, since near-saturation would produce overexposure and positive skewness while underexposure would be manifested in negatively-skewed histograms. Either type of skewness would reduce the integrated area vs that under a histogram representing well-distributed grey levels. Once ß has been set, it may be possible to set a cutoff value of ß below which probability quantization of the final image's grey levels would not be performed. We will investigate these and other approaches to automating the specification of processing parameters.

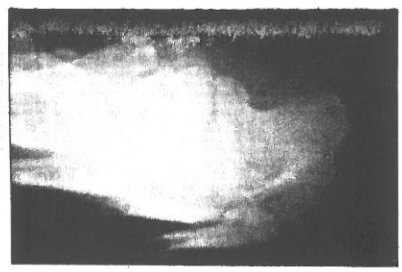

Figure 2: Shows the original ankle image (top) and the processed result (bottom). Viewed from the back of the heel with the ankle flexed and toes pointing left.

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