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Technical Notes

Portal imaging: Performance improvement in noise reduction by means of wavelet processing

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ABSTRACT

This paper discusses the suitability, in terms of noise reduction, of various methods which can be applied to an image type often used in radiation therapy: the portal image. Among these methods, the analysis focuses on those operating in the wavelet domain. Wavelet-based methods tested on natural images – such as the thresholding of the wavelet coefficients, the minimization of the Stein unbiased risk estimator on a linear expansion of thresholds (SURE-LET), and the Bayes least-squares method using as a prior a Gaussian scale mixture (BLS-GSM method) – are compared with other methods that operate on the image domain – an adaptive Wiener filter and a nonlocal mean filter (NLM). For the assessment of the performance, the peak signal-to-noise ratio (PSNR), the structural similarity index (SSIM), the Pearson correlation coefficient, and the Spearman rank correlation (ρ) coefficient are used. The performance of the wavelet filters and the NLM method are similar, but wavelet filters outperform the Wiener filter in terms of portal image denoising. It is shown how BLS-GSM and NLM filters produce the smoothest image, while keeping soft-tissue and bone contrast. As for the computational cost, filters using a decimated wavelet transform (decimated thresholding and SURE-LET) turn out to be the most efficient, with calculation times around 1 s.

Introduction

Portal imaging is used in external radiotherapy to verify and correct the patient positioning during the treatment stage. The treatment beam itself is used for image formation, thus giving the portal image a unique feature among the systems usually employed to verify patient positioning: the use of the treatment beam for image formation provides direct visualization of the anatomical structures that are irradiated. Moreover, portal imaging can be also used for real-time monitoring of treatment (e.g. gating or tracking applications) [1].

The high energy of the particles used in radiotherapy (6–18 MV) causes the reduction in the quality of portal images [2,3]. Imaging systems show a much lower detection efficiency for this kind of beams than for beams in the radiodiagnostic energy range (80–120 keV). Noise is another factor that limits the quality of the portal image. Given that both beam generation and beam interaction with the detector sensitive material are statistical processes, the noise stems from the radiation beam itself. Later, electronic noise is added during signal acquisition and conditioning stages. Moreover, noise has a big impact on video applications which involve portal imaging systems, due to the low detection efficiency and the limited radiation fluence that treatment units can provide [1].

Noise reduction is a fundamental topic in the image processing field. Denoising methods base their operation on the knowledge of the image and noise characteristics, especially those that differentiate them. For portal images, the study in Reference 4 shows similarities in the statistical distribution of wavelet coefficients between the portal and natural images. The similarities are found in both the marginal distributions of coefficients and the joint and conditional distributions between subbands of the wavelet decomposition. Noise distribution in the wavelet domain is clearly Gaussian, but for portal images the tails of the distribution deviate from Gaussian and approach Generalized Laplacian, as natural images do [5].

The conditional distributions for the wavelet coefficients of portal images show how conditional variance increases with the value of the conditioning variable [4]. Thus, large amplitude coefficients tend to be close to other high-amplitude coefficients. This trend is also evident between coefficients in different subbands. For the noise of portal imaging systems, a Gaussian distribution was found in both image and wavelet domains, along with a remarkable absence of statistical dependencies between wavelet coefficients.

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In this paper we investigate the efficiency of various noise reduction methods when applied to portal images. The main objective of the study is to compare methods operating in the wavelet domain with methods operating in the image domain. The methods discussed are applied to images of different anatomical sites, to which different amounts of noise have been previously added. The approach followed to study denoising performance is the same as that followed in other image modalities. Portal images of real patients are used instead of phantom images because the statistical characteristics of the images are a fundamental issue, and the texture and correlation properties of both kinds of images are quite different.

Materials and methods

All portal images used in this work were obtained in a linear accelerator Clinac DHX 2100 (Varian Medical Systems). The portal imaging system, the Portal Vision aS500 (Varian Medical Systems), is based on an amorphous silicon detector with an array of 384×512 transistors, which results in a pixel size of 0.784×0.784 mm^2. The system includes a metal foil and a phosphor screen for converting X-ray photons into the visible spectrum. The energy of the beam was 6 MV, and the monitor units (MU) per image ranged between 1.2 and 1.5. The calibration of the Linac gives 1 cGy in d_{max} per MU, in a calibration set-up (100 cm SSD and 10×10 cm^2 field size in water).

The study considered 4 portal images: pelvis (anteroposterior and lateral projections), chest and skull.

Performance assessment

A Gaussian white noise n is added to each portal image x to get the corresponding noisy image y. Then, each denoising method is applied to y and the resulting estimation $\breve{x}$ is compared to x by different metrics. The peak signal to noise ratio (PRNR) is defined as

$$PSNR = 10\log_{10}\frac{Range^2}{MSE}, \tag{1}$$

where *Range* is the difference between the maximum and minimum pixel values of image x, and MSE is the mean square error $MSE = \frac{1}{N}\|x - \breve{x}\|^2$. The structural similarity index (SSIM) [6] is calculated as

$$SSIM(x, \breve{x}) = \frac{(2\mu_x\mu_{\breve{x}} + C_1)(2\sigma_{x\breve{x}} + C_2)}{(\mu_x^2 + \mu_{\breve{x}}^2 + C_1)(\sigma_x^2 + \sigma_{\breve{x}}^2 + C_2)}, \tag{2}$$

where μ_x is the mean value of the image pixel x and represents its luminance, σ_x is the standard deviation of x and represents its contrast, and $\sigma_{x\breve{x}}$ is the correlation coefficient between images x and $\breve{x}$ and measures the structural similarity between both images. The constants C_1 and C_2 are small positive values that provide stability to the index avoiding singularities in the denominator.

Besides the PSNR and SSIM, the Pearson and Spearman ρ correlation coefficients between $\breve{x}$ and x are calculated. Finally, to complete the assessment of each noise reduction method, the computational cost is determined. The running time shown in the "Results" section is obtained as the average of five separate calculations for each of the cases. The calculations were performed on an Intel Core 2 Duo TM6400 processor with a frequency of 2.0 GHz, and the denoising algorithms were implemented in MATLAB (The Mathworks Inc, Natick, MA).

The amounts of noise added to the portal images give rise to three sets of images with PSNR values of 25 dB, 30 dB and 35 dB, respectively. Figure 1 shows a 3×3 checkerboard composed by alternating the original x image and a noisy (PSNR = 25 dB) y image.

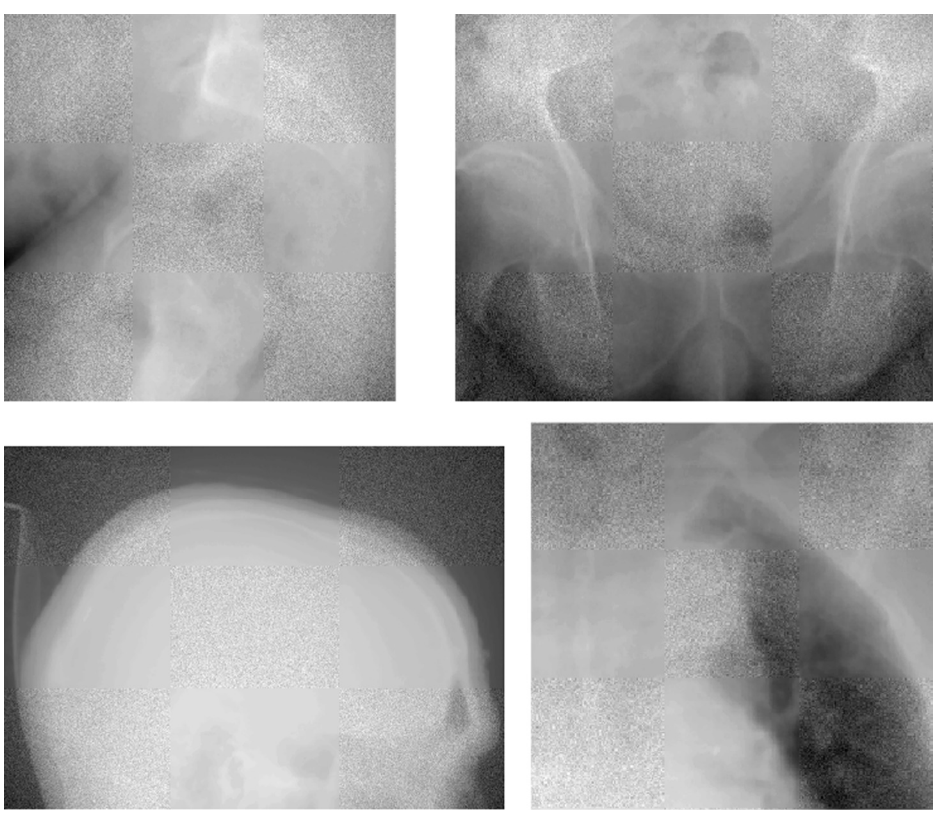

Figure 1. Checkerboards of size 3×3 alternating portal images before and after adding noise (PSNR = 25 dB).

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