Image Enhancement for Concrete Bridge Inspection with Portable 950 keV/ 3.95 MeV X-ray Source

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Abstract: The use of portable and high-energy x-ray system can provide a very promising approach for the inspection of aged concrete structures. However, due to the effect of large scattering of low-energy x-ray in a thick concrete, the noise properties and contrast of the radiographic images need to be optimized to ensure reliable interpretation. Therefore, in order to improve the inspection ability, an image denoising method with the combination of wavelet and curvelet transform and image contrast enhancement approach using neighborhood operation is proposed to enhance the x-ray image for concrete bridge inspection in this work. To investigate the performance of this method for our system, we have performed several experiments with simulated and experimental data. It shows that the proposed image processing method can significantly improve the inspection performance.

Keywords: Concrete structure inspection; X-ray image; Image denoising and enhancement

1. Introduction

The use of 950keV/3.95MeV X-band (9.3GHz) portable linac X-ray sources can provide a very promising approach for the inspection of aged concrete structures [1]. However, due to the effect of large scattering of low-energy x-ray in a thick concrete, the noise properties and contrast of the radiographic images need to be optimized to ensure reliable interpretation. Therefore, an additional digital image processing method is needed to enhance the images. Presently, there are several simple methods (such as histogram equalization and gray transform) that can be used to enhance the image contrast. However, such methods are not very effective for our system because of their poor noise properties. A good alternative here could be the use of wavelet-based or curvelet-based multi-resolution analysis because the noise usually has a different spatial regularity compared with that of the image structures [1, 2]. Besides, this kind of multi-resolution analysis can also be applied to enhance the image contrast by thresholding on the wavelet or curvelet coefficients or using edge stretching method. The wavelet-based multiscale edge stretching method has also been introduced as a very good approach for image enhancement in the previous researches [2, 3]. It is based on a concept of multiscale edge representation with a particular class of cubic-spline wavelets proposed by Mallat and Zhong [3].

However, wavelet transform (WT) demonstrates good performance at representing point singularities. It does not work so well in higher dimensions due to the lack of geometrical property of wavelet. In contrast, curvelet transform (CT) takes the form of highly anisotropic elements with high directional sensitivity. Therefore, it leads to a more accurate image representation than through WT. CT does not lead to an optimal sparse representation of the isotropic parts of the image compared to WT, and consequently denoising based on filtering in curvelet domain does not perform as well as wavelet denoising. Therefore, a combined curvelet-wavelet (CW) approach with the advantages provided by both techniques may potentially lead to improved performance.

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Besides, in order to identify the steel reinforcement in the very low contrast image, we also developed an image contrast enhancement approach with using neighborhood operation.

2. **Image denoising method**

2.1 Combined curvelet-wavelet denoising method

As previously introduced, WT is good at handle small isotropic (such as noise), whereas CT works well at restore anisotropic structures (such as edges). In order to combine the advantages of wavelet denoising (WD) and curvelet denoising (CD), a combined CW denoising method is illustrated in Fig. 1.

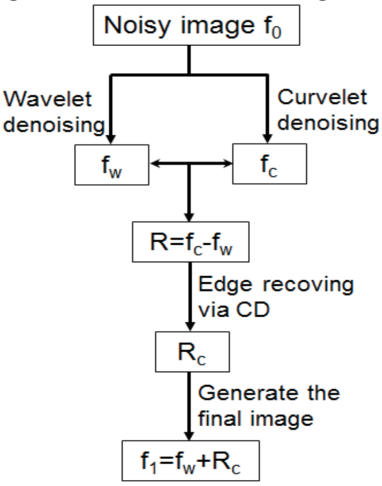
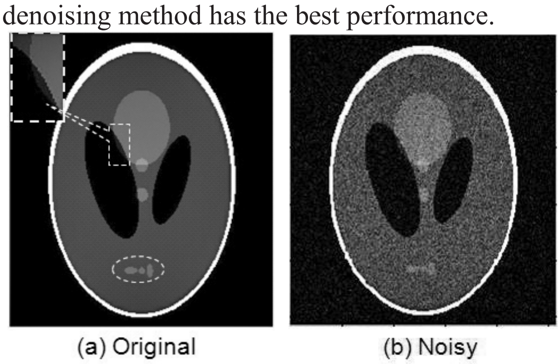


Fig. 1 Combined CW denoisng scheme

2.2 Results

Fig. 2 shows the results of denoising of a simulated noisy image with Gaussian filtering, WD, CD and the proposed CW denoising methods. By comparing with the original noise-free image, it can be seen that the CW denoising method has the best performance.



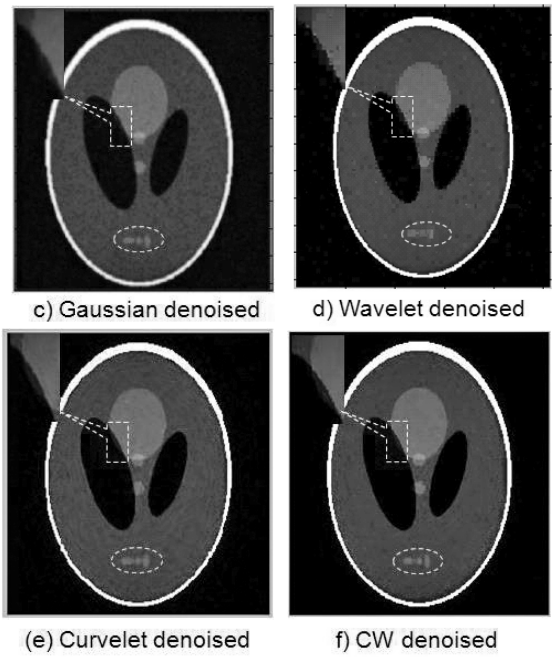


Fig. 2 The results of image denoising with various methods

Fig. 3 shows the result of denoising of a 950 KV x-ray image from a small concrete sample with CW denoising method. However, the noise is significantly reduced, the image seems not become much clear as the contrast is not changed during denoising.

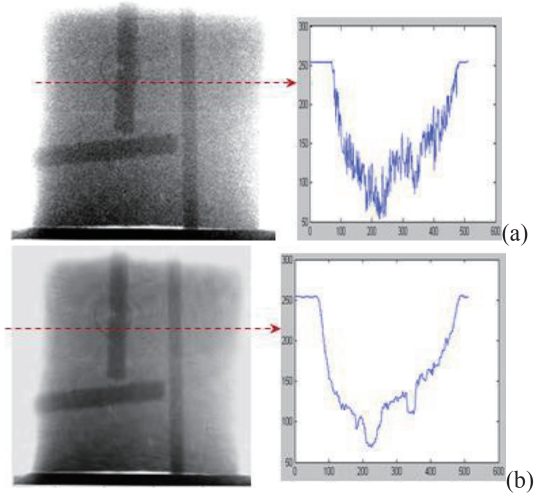


Fig. 3 CW denoising of 950 KV x-ay image from a small concrete sample: (a) original and (b) denoised image and the profile at the dash line of them

3. Image contrast enhancement

3.1 Method of contrast enhancement using neighborhood operation

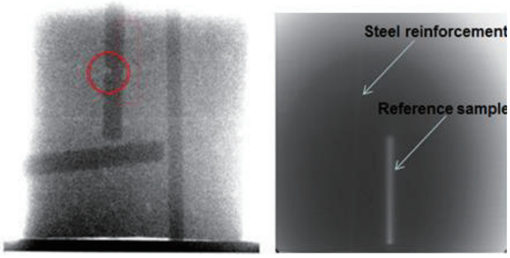
In this work, in order to identify the steel reinforcement in the very low contrast image, we also developed an image enhancement approach with using neighborhood operation. The principle of contrast enhancement using grey level of the neighborhood pixels is shown in Eq. (1).

$$f_2(x,y) = \frac{f_1(x,y) - M_1}{M_2 - M_1} \times M_g \qquad (1)$$

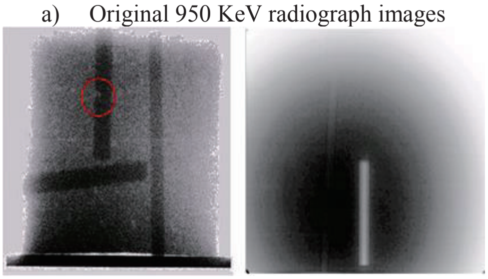
M_1 is the minima and M_2 is the maxima of the input image f_1 among the neighborhood pixels, Mg is the maximum gray level value of the input image.

3.2 Experimental results

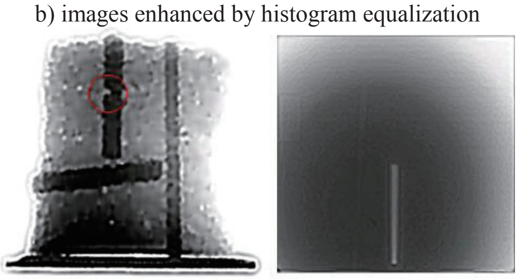
Fig.4 shows the results of image enhancement for two noisy 950 KeV radiograph images measured from a small concrete sample and a large concrete bridge sample with various methods. It can be observed in Fig. 4(b) that the contrast of image enhanced by histogram equalization is slightly better compared with that of the original image; however, the noise is magnified and the ends of steel bars near the image boundaries tend to disappear in noise. Fig. 4(c) shows the result of applying the wavelet-based edge stretching method. It can be seen that the this method works very good for image with good contrast, but it does not work for very low contrast image. Fig. 4(d) is the result with using neighborhood operation. It can be observed that this method works very well, especially for the very low contrast image; the edge of the steel bars become much clear, however some noise is also enhanced because of the neighborhood-based contrast enhancement.



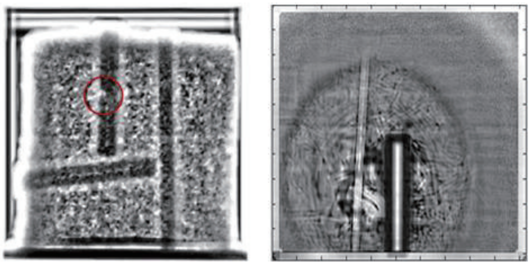
a) Original 950 KeV radiograph images



b) images enhanced by histogram equalization



c) images enhanced by wavelet-based edge stretching



d) images enhanced using neighborhood operation

Fig. 4 Results of enhancement x-ray image with various methods

4. Conclusions

In order to improve the inspection ability of the 950 KV / 3.05 MeV x-ray system for concrete structure inspection, an image denoising method with the combination of wavelet and curvelet transform and an image contrast enhancement approach using neighborhood operation is developed in this work. Several experiments with simulated and experimental data show the proposed image processing methods can significantly improve the inspection performance.

References

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