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A Multiscale Contourlet Transform Denoising Algorithm for X-ray Gastrointestinal Digital Image

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Abstract: Although, X-ray gastrointestinal imaging system is a necessary medical diagnosis method, various noises will unavoidably appear in the image when X-ray gastrointestinal imaging is performed. An effective method to improve image quality is to reduce adverse effect on the image brought by noises, so as to de-noise X-ray gastrointestinal image. According to the features of X-ray gastrointestinal images with high resolution and complex details, Contourlet transform, which is capable of expressing high dimension geometry features such as image edges, details, etc., is used to propose an X-ray gastrointestinal image de-noising algorithm based on Multi-resolution Contourlet transform. This algorithm introduces cycle-spinning into de-noising process, thus, the "nick" problem brought by Contourlet transform hard threshold de-noising is overcome. Result shows that, for actual X-ray gastrointestinal image, this algorithm can both retain details in gastrointestinal images and obtain good de-noising effect and at the same time the calculation efficiency is high.

Key words: X-ray gastrointestinal image, multi-scale geometric analysis, contourlet transform, cycle spinning

INTRODUCTION

X-ray was discovered by Germany scientist, Rontgen (1986). It is well-known for its application in medical diagnosis. For example, when somebody's physical fitness is examined, the doctor usually takes an X-ray image of his/her chest to determine whether the inner pleural is healthy. Another example is X-ray gastrointestinal imaging. X-ray imaging technique has its superiority in dynamic inspection and small lesions inspection, mainly because medical X-ray imaging equipment has high spatial resolution that makes it possible to display the detail information of tissues at the scale of less than 0.1 mm and high temporal resolution at the order of millisecond which makes it possible to observe the activity of human organs (Eastman Kodak Company, 1998, 2006). As a branch of X-ray imaging examination, digitalized X-ray gastrointestinal imaging can relieve people's pains of conducting traditional gastrointestinal endoscope examination; therefore, it is experiencing fast development in the gastrointestinal diagnosis in the medical field (DICOM, 1997; Nema, 2001).

Actually, the acquired gastrointestinal images are unavoidable corrupted by noise, because X-ray gastrointestinal imaging system is an integration system of optics, mechanics, electronics and calculation. Especially when the X-ray coefficient of the normal tissue of the stomach is close to the one of the lesion tissue, the detail characteristics in the gastrointestinal image is submerged in strong noise; it has adverse effect on the accurate identification of lesion tissue from gastrointestinal X-ray images. Accordingly, the Contourlet transform based de-noising algorithm for X-ray gastrointestinal images is investigated and some significant results are given.

THE PRINCIPLE OF IMAGING SYSTEM

The principle of X-ray gastrointestinal digital imaging is: X-ray penetrate through human body and the attenuated X-ray beam, which carries the information of the gastrointestinal structure, is transformed into visible light by image intensifier, The visible light from intensifier output screen is focused on the photosensitive surface of CCD (Charge Coupled Device) digital camera and is transformed into electrical signals by photoelectric conversion, The analogue electrical signals representing an image is transformed into digital signals and by A/D convertor and finally, The output signals are acquired, processed and stored in computer. Digitalized

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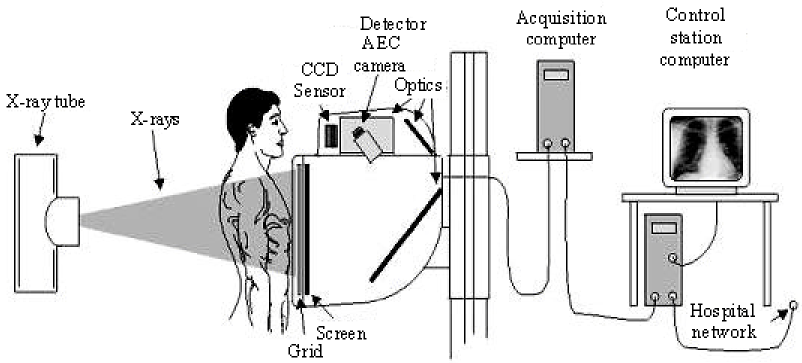

Fig. 1: The theoretical diagram of X-ray gastrointestinal imaging system based on CCD digital camera

X-ray gastrointestinal image can be displayed in monitor after D/A convention, providing doctors with gastrointestinal lesion information for diagnosis, treatment or consultation purpose Fig. 1.

NOISE SOURCE ANALYSIS OF IMAGING SYSTEM

According to the possible sources of noise in imaging process as shown in Fig. 1, the noises generated in the imaging system are classified into 2 categories, system inherent noise and system random noise.

The inherent noise of the imaging system include CCD noise, noise induced by nonuniform response of the imaging screen and image vignetting noise. CCD, as an image detector, outputs space sampling discrete signals, which are interfered by various noises, such as photon noise, shot noise, dark current noise, etc. The nonuniform responses of imaging plate to X-ray induce pseudo defects such as significant stripes, light spots, dark spots and bubbles. Through image procession, these pseudo defects can be removed. After the image vignetting is treated, the image gray level will be corrected and the visual effect will be improved.

Although, the randomly distributed noises of the imaging system are difficult to predict, they can be identified using probability and statistics and then classified as positive impulse noise, salt and pepper noise, or Gaussian noise. When the scattering X-ray acts on the CCD chip, a lot of positive noises which are randomly distributed in spatial position and shown as positive impulse are produced. These noises have great impact on the quality of gastrointestinal images and their quantity and amplitude will increase along with the time and energy of the radiation applied on CCD. Salt and pepper noise can produce impulse noise like black and white spots, which causes trouble to the following tasks as extracting and identifying characteristic information from images. In X-ray digital imaging, the noises which are Gaussian distributed in space in every dimension are known as Gaussian noise. Not only is every different gray level of every pixel of the Gaussian-noise-polluted X-ray gastrointestinal image affected, but also the pollution degree of the gray level of the same pixel is of large difference. Define $n(t) \sim N(0, \sigma^2)$ as a Gauss stationary stochastic process, $E(t)$ as the expectation value of random variable t, $D(t)$ as variance, then, $E[n(t)] = 0$ and $D[n(t)] = \sigma^2$, the auto-correlation of $n(t)$ is $E[n(u)n(v)] = \delta(u-v) = \sigma^2$, its wavelet transform is Xu *et al*. (1994) and Ramin and Hayder (2002):

$$\begin{aligned} W_n(s,t) &= n(t) * \psi_s(t) \\ &= \int_{-\infty}^{+\infty} n(u)\psi_s(t-u)du = \sum_u n(u)\psi_s(t-u) \end{aligned} \quad (1)$$

For a given scale s, $W_n(s,t)$ is a random process of t, then

$$|W_n(s,t)|^2 = \sum_u \sum_v n(u)n(v)\psi_s(t-u)\psi_s(t-v) \quad (2)$$

Thereby,

$$\begin{aligned} & E[|W_n(s,t)|^2] \\ &= \sum_u \sum_v E[n(u)n(v)]\psi_s(t-u)\psi_s(t-v) \\ &= \sigma^2 \sum_u \sum_v \delta(u-v)\psi_s(t-u)\psi_s(t-v) \\ &= \sigma^2 \sum_u |\psi_s(t-u)|^2 \\ &= \frac{\sigma^2}{s} \sum_u |\psi(u)|^2 = \frac{\sigma^2 \|\psi(t)\|^2}{s} \end{aligned} \quad (3)$$

Equation 3 shows that, the mean value of $|W_a(s,t)|^2$ gradually decreases with the increase of scale s; that is to say, the average power of $W_a(s,t)$ decrease with the increase of scale.

Besides, the variance of Gaussian white noise $|W_n(s,t)|^2$ is

$$D[|W_n(s,t)|^2] = E[|W_n(s,t)|^4] - (E[|W_n(s,t)|^2])^2 = \frac{3\sigma^4 \|\psi(t)\|^4}{s^2} \quad (4)$$

Through analysis of Eq. 4, the variance of $|W_n(s,t)|^2$ decreases as scale s gradually decreases and this provides theoretical basis for multi-scale Contourlet transform based de-noising algorithm for X-ray gastrointestinal imaging.

CONTOURLET TRANSFORM AND ITS IMAGE DE-NOISING ALGORITHM

Contourlet transform: Contourlet transform, proposed by M N Do, etc. is a multi-resolution, localized, multi direction representation method for image (Do, 2003; Po and Do, 2003; Stack *et al*., 2002). It is also called Pyramidal Directional Filter Bank (PDFB). First, LP (Laplace) transform is applied to decompose the image to capture singular points; second, DFB (Directional Filter Bank) is used to combine all the singular points in the same direction into one coefficient and the base support interval of DFB have a "strip" structure whose length-to-width ratio changes with scale. Compared with wavelet analysis, Contourlet transform can represent images more "sparsely". The principle of Contourlet transform is shown in Fig. 2. Also, 3 layers decomposition of a forest image is shown in Fig. 3.

Cycle spinning contourlet de-noising algorithm for images: Similar to wavelet de-noising, an image is not shift-invariant after it is cyclically shifted. Between its contourlet decomposition coefficients and its original coefficients, there is no corresponding translation relationship and because the image energy distributes among lots of bases, many contourlet decomposition coefficients have nonzero value. Most decomposition coefficients have small amplitudes, so, when threshold de-noising is applied to one image, the reconstructed image will appear pseudo component (visual fake image); especially, the Gibbs phenomenon will appears at the neighborhood of singular points and in the de-noised images after reconstruction the amplitude values will

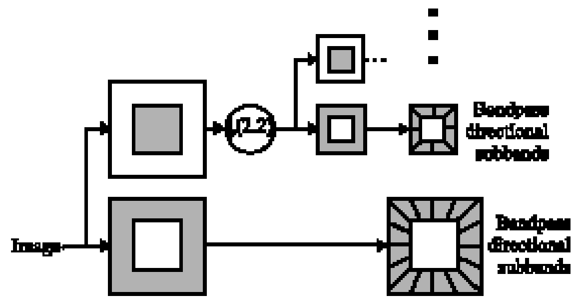

Fig. 2: A schematic diagram of contourlet transform

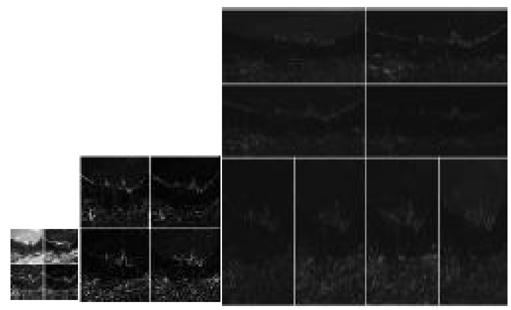

Fig. 3: The 3-level decomposition of Forest image

vibration up and down at the neighborhood of the singular point. Due to the localization characteristics of Contourlet transform, the vibrating amplitudes of Gibbs phenomenon is closely related to the position of singular points. To a given filter, it can constrain Gibbs phenomenon in some specific position in the image, so can cycle spinning. By changing the order of the image pixels to change the position of the singular points in the image, the oscillation amplitude is decreased or eliminated and the quality of reconstructed image is improved. Consequently, the process of Cycle spinning Contourlet de-noising can be describe as following steps: first, make image translation for a certain distance; second, apply hard-threshold Contourlet transform de-noising to the translated image; third, through inverse translation, the pixels of the image is restored to its original order and the de-noising process is effectively achieved.

To a N × N two-dimensional image I(x, y), define Cycle spinning operator

$$C_{i,j}(I) = I[\mathrm{mod}(x+I,N), \mathrm{mod}(y+j,N)] \quad (5)$$

The cycle spinning operator is invertible. Its inversion is

$$\left[C_{i,j}(I)\right]^{-1} = C_{-i,-j}(I) \quad (6)$$

Suppose S is the noise image, S = I + n and n denotes noise. Define the following de-noising procedure

$$\hat{I} = C_{-i,-j}(DNCT(C_{i,j}(S))) \tag{7}$$

Where, $\hat{I}$ denotes the result after applying Cycle spinning de-noising to the noise image; DNCT means the process of Contourlet transform, de-noising and reconstruction for two-dimensional images. That is

$$DNCT(f) = T^{-1}\{h[T(f)]\} \tag{8}$$

Where, f denote the two-dimensional image before processing, T denote the decomposition process using Contourlet transform, T^{-1} denote the reconstruction process of Contourlet transform, h is the hard-threshold operator.

A lot of singular points appearing in the image will lead to the following contradiction: While a translation produces the best effect for one singular point, it might produce bad effect for another. Therefore, when there are lot of textures and edges in the image, it is difficult to determine the translation distance which is optimal for all singular points. To solve this problem, translations are made in certain range and the average is made out of all the results. This process is express as

$$\hat{I} = \frac{1}{N_1 N_2} \sum_{i=1,j=1}^{N_1 N_2} C_{-i,-j}(DNCT(C_{i,j}(S))) \tag{9}$$

Where, N_1 and N_2 denote the translation distance in horizontal direction and vertical direction, separately.

RESULTS AND DISCUSSION

To test the feasibility and validity of this de-noising method, "Lena" image with zero mean white noise is used as test image, the size of which is 512×512. Decimated wavelet (Db9/7), traditional Contourlet transform and Cycle spinning Contourlet are used to process the noise image and hard threshold is selected. Only the four sub-bands with minimum scale are processed in Table 1. In visual effect, Contourlet transform de-noising can remove noise and at the same time the image detail (e.g., the texture of the hat in "Lena" image) is well reserved and it is obviously superior than decimated wavelet. ② As for PSNR (Power Signal-to-Noise Ratio), both the traditional Contourlet transform de-noising and the CCT (Cycle spinning Contourlet Transform) de-noising are more effective than traditional decimate wavelet de-noising, but CCT de-noising has higher PSNR and can reduce pseudo Gibbs phenomenon in the image, Fig. 4.③ As for the reliance on the noise variance, the effect of decimated wavelet de-noising is bad when the noise variance is large, whereas the effect of Contourlet transform de-noising is better than decimated wavelet de-noising and CCT de-noising is best.

Table 1: Image's PSNR before and after de noising (Lena + Gaussian white noise)

Noise variance	Noise image	Wavelet	Contourlet	CCT
10	28.1387	30.0004	32.2077	34.4158
15	24.6251	28.9204	30.3986	32.5878
20	22.2153	27.3890	29.1923	31.2330
25	20.2669	26.1662	28.1583	30.1339

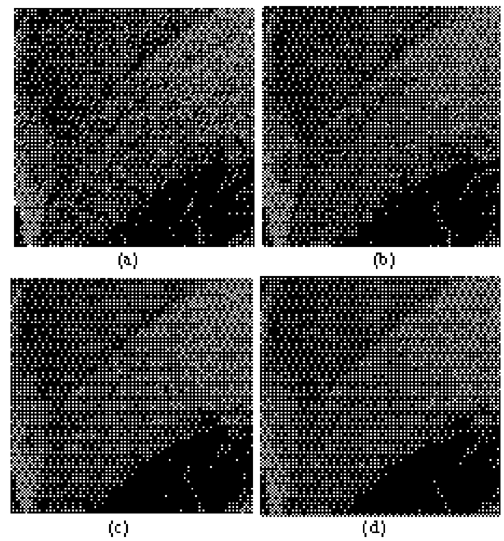

Fig. 4: Images before and after de-noising using different methods, a) noise image, b) wavelet de-noising, c) Contourlet de-noising, d) CCT de-noising

Based on the above research work, this method is applied to filter noise in the X-ray gastrointestinal images. Figure 5, (b-d) are results after 9/7 wavelet de-noising, Contourlet transform de-noising, Multi-scale Contourlet transform de-noising (this method) is applied to the noise image. The proposed method can remove noise and at the same time retain image details and the visual effect is better than wavelet d-noising and traditional Contourlet hard threshold de-noising.

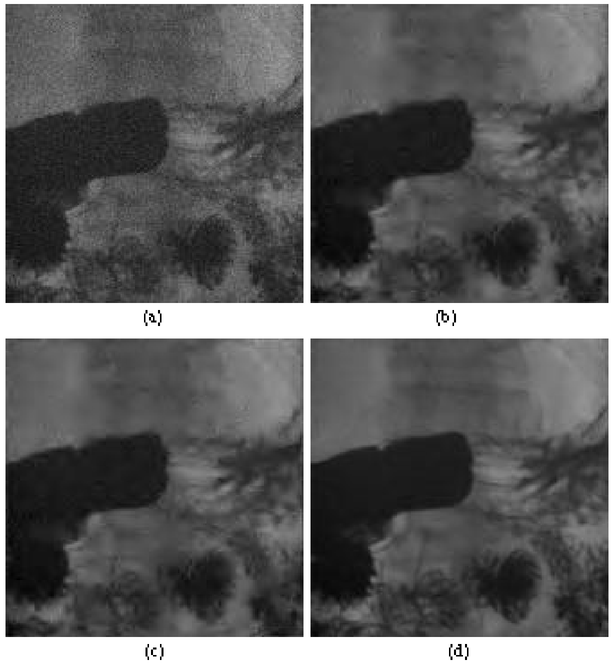

Fig. 5: Results of X-ray gastrointestinal image de-noising, a) actual X-ray gastrointestinal image, b) wavelet de-noising, c) Contourlet de-noising, d) Multi-scale Contourlet transform

CONCLUSION

The fundamental principle of X-ray gastrointestinal imaging system is described in this study and the noise sources and noise types of this system is analyzed. It provide the de-noising algorithm of X-ray gastrointestinal images with the theoretical basis. Aiming at the features of X-ray gastrointestinal images with high resolution and complex details, Contourlet transform, which is capable of expressing image details, is used to propose an X-ray gastrointestinal image de-noising algorithm based on Multi-resolution Contourlet transform. This algorithm introduces cycle-spinning into de-noising process, thus, the "nick" problem brought by Contourlet transform hard threshold de-noising is overcome. The experiment result on the simulation image and actual X-ray gastrointestinal image show that, on the premise that the image detail will not get lost, the multi-scale Contourlet transform algorithm will effectively remove the noise in X-ray gastrointestinal images and meanwhile the calculation efficiency is high. The multi-scale Contourlet transform algorithm applied to remove the noise in X-ray gastrointestinal image is feasible and effective.

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