Neurocomputing 195 (2016) 117–122

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Medical image denoising by parallel non-local means

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ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form
15 June 2015
Accepted 14 August 2015
Available online 8 February 2016

Keywords:
Medical image
Non-local Means
Denoising
Parallel algorithm

ABSTRACT

The generation process of medical image will inevitably introduce certain noises. These noises will degrade the image quality and affect the final clinical diagnosis. Therefore, denoising plays an important role in the pre-processing of medical image before the formal diagnosis and treatment. In this paper, the classical NLM algorithm is improved to denoise medical images by involving a novel noise weighting function and parallelizing. In our experiment, plenty of medical images have been tested and experiment results show that our algorithm can achieve better results and higher efficiency compared with the original NLM method.

1. Introduction

Image denoising is one of the most important operations in computer vision. It is widely used for preprocessing various images, such as common images and MRI. During the generation process, noises will inevitably be introduced into medical images, decrease the image quality and bring lots of inconveniency for the doctor's diagnosis. Therefore, the image denoising becomes an urgent problem to be sovled.

As an important and basic procedure of image processing, denoising has been studied extensively and a lot of related approaches have been proposed, such as Gaussian filter, Wiener filter, wavelet [1–5]. However, most of denoising algorithms will blur the image details when they suppress image noise. NL-Means proposed by Buades [6] is one of the state-of-the-art algorithms for denoising. NL-Means algorithm takes advantage of plenty of redundant information in the images. The key issue of NL-Means algorithm is to choose the weighted kernel function. In this paper, we propose a novel medical image denoising approach which is based on traditional NL-means algorithm. Our approach combines the inherent characteristics of kernel function with the Gaussian kernel to infer a more appropriate weighted kernel function. Moreover, our approach is more suitable to be paralleled for higher efficiency.

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http://dx.doi.org/10.1016/j.neucom.2015.08.117
0925-2312/

2. Related work

The purpose of image denoising is to reduce the image noise. The denoising methods can be classified into spatial domain or image transform domain. The former is one kind of algorithm for local spatial domain processing. The image will be blurred after the neighborhoods are averaged. The latter is to convert the image from the spatial domain to the transform domain. And then the coefficients in the transform domain is processed. Finally, inverse transformation is applied to convert the image back to the spatial domain. There are many transform methods for converting images from space to transform such as Fourier transform, Wavelet transform, Ridgelet transform and so on. However, the current transform approaches can not satisfy the requirements of medical image denoising.

During medical imaging, a variety of factors will result in degradation of image quality mainly by imaging or reconstruction process noise such as motion artifacts, physical system artifacts, noise artifacts. Traditional noise reduction methods are mostly based on a fixed designed noise model and difficult to solve the shortcomings of medical ultrasonic image fundamentally especially for black and white B-mode ultrasonography. In theory, the ultrasound image is multiplicative speckle noise, not only depends on the organizational structure of the organ imaging, but also on the mode of transmission of the acoustic signal, more in line with a hybrid noise model [7,8]. Most of noise reduction methods for MRI based on Gaussian noise model, ignore its inherent Rician distribution [9]. The smoothness will weaken some important image edges and texture, leading to misdiagnosis and missed diagnosis of some diseases.

In the acquisition and transmission of medical image, the image will be subject to various forms of noise interference. In recent years, a number of new filtering technology is drawing attention from scholars and applied to medical image noise [6,10,11]. A. Buades [6] proposed non-local means filter algorithm which took into account as many similarities structural information. However, it has some disadvantages, such as time-consuming and inadequate pixel searching. There are some improved NLM filtering algorithm, such as the robust and fast non-local means algorithm [12], an improved algorithm based on kernel regression [13], Based on Singular Value Decomposition and K-means clustering algorithm for adaptive improvements [14], a moment-based nonlocal-means algorithm [15,16]. These improved algorithms have achieved good denoising effect. However, when these algorithms are applied to medical images, the result is not so good.

To improve the performance of NLM denoising algorithm, this paper presents an improved algorithm based on parallel NLM medical image denoising, and the experiments demonstrate the effectiveness and feasibility of our algorithm.

The rest of this paper is organized as follows. The noise distribution and estimation in medical images are depicted in Section 3.1. The improved adaption to parallel NL-Means denoising method in Section 3.2. GPU-based parallel non-local means denoising algorithm in Section 3.3. The supporting experimental results of improved NL-means algorithm compared to other denoising methods under various conditions are illustrated in Section 4. Finally, concluding remarks are given in Section 5.

3. Parallel NL-Means denoising

3.1. Distribution and estimation in medical images

There are some visual noises in medical images. This degrades the image quality and also affects the image analysis, classification and recognition. Even people can not make the right judgments because of noise.

Medical image noise can be considered as the image that does not reflect the characteristics of the organ or tissue pathology region texture. The following describes the mechanism and characteristics of some typical medical image noise.

Ultrasound image noise: The ultrasound images (Ultrasound image) generation is based on ultrasonic pulse echo. When the ultrasonic wave propagates in the human body, at the junction of the body's tissues or at different uneven nature of the organization, it will produce reflections and refractions. So different intensity of the echo signal will be produced. These echo signals collected by the respective transducer circuit are converted into electrical signals with different intensities. Finally, the circuit converts these electrical signals to display different gray scale image signals.

Magnetic resonance image noise: MRI (Magnetic Resonance Imalting) utilizes the principle of magnetic resonance. It places the body while applying a magnetic field in a certain frequency alternating radiofrequency electromagnetic waves on the human body, this will cause to be probed proton resonance and resonance signal radiated outwards. Thus for different parts of the body, the proton resonance frequency is different. The generated electromotive force, eventually after the appropriate display circuit is formed of different gray level pixels, to give Magnetic resonance images. Overall, the final magnetic resonance noise can be considered to comply with the Rayleigh distribution additive noise [15]. Its probability density function is:

$$p(x) = \frac{x}{a^2}\exp\left(-\frac{x^2}{2a^2}\right) \tag{1}$$

Infrared image noise: infrared thermography is a non-contact type of non-invasive method to measure surface temperature. It uses infrared radiation imaging principle research body surface temperature. According to the body surface, different temperature distribution form the image of different gray pixel. Factors generating image noise are mainly caused by coherent infrared light effect, so analysis method is similar to the ultrasound image.

X-ray computed tomography noise: X-CT (X-ray computed tomography) is based on an X-ray computer tomography imaging. X-ray scans of the human body surrounded by body parts when imaging X-ray tube enters the body of a cross-section along the lot line. In the injection process, X-rays continue to decay. These measured attenuation data on the computer uses an image reconstruction principle to give each point of the cross section of the X-ray absorption coefficient, which will eventually be converted into different gradation pixels to form the image. X-ray attenuation law can be expressed as:

$$n = n_0 e^{-ud} \tag{2}$$

where n and n_0 is defined penetrating X-ray dose before and after water model. And u is ray attenuation coefficient, d is water die diameter.

X-CT image noise mainly contain quantum noise and electronic noise. The former is mainly produced by the X-ray photons into the image intensifier inhomogeneity and physical factors with CT tube current, the tube voltage, thickness and other closely related. CT scans of different ways and reconstruction algorithms related factors also contribute to X-CT image noise from the probability distribution, so X-CT image noise can be approximated by a Gaussian distribution considered additive noise.

3.2. Adaption to parallel NL-Means denoising method

3.2.1. Non-local mean noising algorithm

In an image, there will always be a lot of redundant information. A typical noise reduction idea is to use the redundant information. The classic neighborhood filtering algorithm is based on this idea. NL-Means algorithm proposed originated in the neighborhood filtering algorithm. As shown in Fig. 1, rectangular field pixel p and $q1$ are more similar than the pixel p and $q2$ of rectangular areas. In fact, the rectangular areas of the pixel p and q2 is not similar in human vision. In an image, adjacent pixels are most likely to have similar rectangular areas. But most of the pixels in the same column, for example, p will have its similar rectangular areas [17]. So in NL-Means algorithm, the value of one pixel is based on the noise reduction of the similar rectangle area.

For a discrete noise images $v(i) = \{v(i), i \in I\}$, Gray estimation N $L(v)(i)$ of pixel i is calculated by a weighted average of all pixels:

$$NL(v)(i) = \sum_{j \in I} w(i,j)v(j) \tag{3}$$

where the weight $w(i,j)$ determine the similarity of the pixel i and a pixel j with valid range in [18] and sum of weight is 1. The pixels i and j with similar intensity determine similarity gray vector between $v(N_i)$ and $v(N_j)$, and N_n is the n-centered rectangular neighborhood. Gaussian-weighted Euclidean distance $d(i,j)$ is used to measure the similarity of each neighborhood between the gray value matrix and defined as:

$$d(i,j) = \| v(N_i - v(N_j)) \|_{2,a}^2 \tag{4}$$

where a is greater than zero and is difference between the standard Gaussian kernel. $v(N_i)$ gray pixels with similar