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Smoothing of ultrasound images using a new selective average filter

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ABSTRACT

Ultrasound images are strongly affected by speckle noise making visual and computational analysis of the structures more difficult. Usually, the interference caused by this kind of noise reduces the efficiency of extraction and interpretation of the structural features of interest. In order to overcome this problem, a new method of selective smoothing based on average filtering and the radiation intensity of the image pixels is proposed. The main idea of this new method is to identify the pixels belonging to the borders of the structures of interest in the image, and then apply a reduced smoothing to these pixels, whilst applying more intense smoothing to the remaining pixels. Experimental tests were conducted using synthetic ultrasound images with speckle noisy added and real ultrasound images from the female pelvic cavity. The new smoothing method is able to perform selective smoothing in the input images, enhancing the transitions between the different structures presented. The results achieved are promising, as the evaluation analysis performed shows that the developed method is more efficient in removing speckle noise from the ultrasound images compared to other current methods. This improvement is because it is able to adapt the filtering process according to the image contents, thus avoiding the loss of any relevant structural features in the input images.

1. Introduction

According to (Fish, 1990), a sound wave is a mechanical disturbance that crosses an environment resulting in the vibration of the particles presented. The frequency of this vibration is measured in Hertz and when it is higher than 20 KHz, it is called ultrasound which cannot be perceived by the human ear. Ultrasound waves, also known as beams, may be longitudinal or transverse. For transverse waves, the direction of disturbance is perpendicular to the propagation, whilst in longitudinal waves the disturbance is in the same direction as the propagation. In both cases, the waves are characterized by wavelength, period, amplitude and frequency, and their transmission velocity depends on the density of the object that receives the ultrasound waves which are produced and detected by a transducer.

In medical ultrasound imaging, a transducer generates a quantity of ultrasound waves at a pre-defined frequency that are directed onto tissues and organs. The tissues and organs reflect part of these waves and absorb the remaining part. The reflections may be grouped into two main categories according to the reflecting surface: specular reflections occur when the surface hit by the ultrasound waves is larger than the wavelength, and scattering occurs when the surface hit by the ultrasound waves has smaller dimensions than the wavelength used. In the case of scattering, the reflection of the same wave occurs in several directions and therefore only a small part of the wave emitted by the transducer will be received back. Irregular surfaces may also generate the scattering effect (Fish, 1990).

During ultrasonic imaging, a large number of ultrasound wave beams are emitted and a considerable quantity of scattering usually occurs. Besides generating a loss of the signal emitted by the transducer, the scattering of an ultrasonic beam also causes the scattering of other beams due to collisions with other scattered waves. These lost signals are known as echoes and some of them produce artifacts in the resultant image, called “speckle noise”, which degrades the spatial resolution and contrast in the image (de Araujo, Constantinou, & Tavares, 2014). These echoes that are displayed during the ultrasound examination of organs and other structures captured by the transducer are commonly quantified in shades of grey in which the strongest echoes are represented by higher intensities of grey and the faintest echoes by the lower

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intensities, i.e. tending to white and black, respectively. Moreover, interpolation and filtering techniques and logarithmic compression may be used to obtain bi-dimensional images, leading to the loss of some signals received by the transducer and therefore, to images of lower quality (Mari & Cachard, 2007). Despite the usual low quality of the images generated by ultrasonic examinations, this imaging modality is widely adopted for the analysis and diagnosis of organ and tissue dysfunctions because it provides information about the geometry and behaviour of structures in real time without any side effects for the patients (Wu, Lo, Cheng, & Lin, 2010).

As discussed in (Mateo & Fernández-Caballero, 2009), several well-known techniques have been used to smoothing speckle noise in medical images. Among these techniques, some are applied in the spatial domain of the images, and others are used in the frequency domain. The first group, to which the algorithm proposed here belongs, are based on well-known image filtering techniques such as average filtering (Zhang & Wang, 2015), median filtering (Verma, Singh, & Thoke, 2015) and anisotropic diffusion based filtering (Santos et al., 2013). The study conducted in (Mateo & Fernández-Caballero, 2009) allows one to conclude that the smoothing algorithms depend heavily on the application. Thus, smoothing algorithms can be incorporated as solutions for noise removal taking into account the type of noise involved, which is strongly related to the image acquisition technique used.

The common artifacts in ultrasound images, such as speckle noise, may give rise to false information of the imaged structures, and so, these artifacts must be removed to avoid any misinterpretations. Based on these facts, a new approach to perform the selective smoothing of images affected by speckle noise is proposed here. This proposal is mainly concerned with medical ultrasound images. The proposed algorithm uses the intensity of the radiation of the image pixels being smoothed in an attempt to select those that potentially belong to the borders of the structures of interest allowing, therefore, the adaptive smoothing of the input image by using an average filter with different levels of smoothing.

Usually, an ultrasound image is composed of dissimilar regions of interest affected by speckle noise of different intensities. Thus, applying different smoothing filters or the same smoothing filter but with different smoothing levels in each region of the input images can lead to more competent smoothing of the corrupted images (Thaipanich, Oh, Wu, Xu, & Kuo, 2010). Average filtering was adopted in this study as the smoothing filter since it is a low-pass filter in which high frequencies are filtered and therefore, the relevant details in the internal regions of the imaged structures are preserved (Gonzalez & Woods, 2006).

The rest of this manuscript is organized as follows: related works are presented in the next section. The proposed selective smoothing algorithm is described in Section 3. The experiments and discussion are presented in Section 4. Finally, the conclusions and considerations for future works are pointed out in the last section.

2. Related works

Noise removal is a common task in digital image processing and it has been widely studied. This task is included in commonest image pre-processing pipelines and aims to restore the relevant image information corrupted by noise. Hence, an efficient smoothing algorithm is expected to produce an image from the noisy input image that is as similar as possible to the ideal image, i.e. the original image without any noise (Thaipanich et al., 2010).

The presence of noise is common in ultrasound images and interferes severely with, for example, the segmentation, interpretation and classification, i.e. the image analysis, of the anatomical structures (Amirmazlaghani & Amindavar, 2012; Lee et al., 2012). The main noise in ultrasound images is from the overlapping and deviation of sound waves emitted and received by the ultrasound transducer used. Thus, the study of noise reduction techniques for attenuating the noise effects is critical to implement competent computational algorithms designed to improve the quality of the corrupted images. This improvement is particularly crucial to ensure that the segmentation and analysis of the imaged structures can be successfully achieved by computational methods (Narayanan & Wahidabanu, 2009).

In recent years, different computational image processing techniques have been proposed for noise removal, including techniques based on Gaussian filters (Adams, Gelfand, Dolson, & Levoy, 2009; Yang, Wang, Qu, & Fu, 2011), differential equations (Aubert & Aujol, 2008; Barcelos, Boaventura, & Silva, 2003; Coupé, Manjón, Robles, & Collins, 2012; Huang, Ng, & Wen, 2009; Ghita & Whelan, 2010; Ghita, Ilea, & Whelan, 2012) and multi-resolution processing (Jansen, 2001). Additive and speckle noises are the main types of noise found in ultrasound images. In general, removal of speckle noise is more complex and therefore, speckle noise is commonly treated as additive noise. Hence, several studies on speckle noise removal have used similar approaches to the ones adopted for smoothing images affected by additive noise: for example, Jin and Yang (2011) proposed a new variational model for the removal of speckle noise in ultrasound images based on the model developed by Rudin, Osher, and Fatemi (1992) to remove additive noise. Other variational models have been adopted for the removal of this kind of noise. Aubert and Aujol (2008) proposed a new nonconvex variational model based on the classic Maximum A Posteriori (MAP) regularization technique to reduce the interference caused by speckle noise in Synthetic-Aperture Radar (SAR) images. In their approach, the speckle model considered that an image affected by speckle noise is a result of its ideal version multiplied by a noise component. Huang and co-authors (Huang et al., 2009) proposed a variational model based on the Total Variation method to overcome the problem of speckle noise removal. The authors reported results similar to those obtained by the method proposed by Aubert and Aujol (2008). These proposals may get good smoothing results, but the parameter that controls the smoothing process must be very accurately defined. However, the setting of this parameter is generally challenging as it strongly depends on the type of image to be smoothed and on the structures it contains.

Other studies are based on the application of the Wavelet transform for image noise removal (Chang, Member, Yu, Member, & Vetterli, 2000a; Chang, Yu, & Vetterli, 2000b; Pizurica, Zlokolica, & Philips, 2003). In general, these smoothing algorithms can be summarized in three steps. For example, the algorithm proposed by Pizurica et al. (2003) begins by processing the original image using the discrete Wavelet transform, then the desired smoothing operation is performed in the frequency domain and finally, the inverse Wavelet transform is applied to obtain the smoothed image. The advantage of using this kind of approach is that the smoothing of different layers, at different resolutions of the original image, allows the smoothing process to be conducted in such a way that it preserves the specific features in the input image. However, the accuracy and the efficiency of the smoothing depend strongly on the second step of the method and of the type of images to be smoothed.

Approaches based on Gaussian filters are also commonly used in image smoothing (Adams et al., 2009; Yang et al., 2011). These filters can obtain good results when applied on images with homogeneous regions, but they can lead to excessive loss of information on the borders of structures presented. Such filters are usually developed using a Gaussian function as a convolution kernel, and by recalculating the values of the image pixels based on the convolution of an n-sized window. The intensity of smoothing is controlled by a constant that represents the maximum standard