Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–15, 2015

0301-5629/$ - see front matter

http://dx.doi.org/10.1016/j.ultrasmedbio.2014.12.020

● *Original Contribution*

BAS-RELIEF MAP USING TEXTURE ANALYSIS WITH APPLICATION TO LIVE ENHANCEMENT OF ULTRASOUND IMAGES

Huarui Du,* Rui Ma,† Xiaoying Wang,‡§ Jue Zhang,*§ and Jing Fang*§

*College of Engineering, Peking University, Haidian District, Beijing, China; †VINNO Technology (Suzhou) Company, Ltd., Suzhou, China; ‡Department of Radiology, Peking University First Hospital, Xicheng District, Beijing, China; and §Academy for Advanced Interdisciplinary Studies, Peking University, Haidian District, Beijing, China

(*Received* 22 *July* 2014; *revised* 9 *December* 2014; *in final form* 15 *December* 2014)

Abstract—For ultrasound imaging, speckle is one of the most important factors in the degradation of contrast resolution because it masks meaningful texture and has the potential to interfere with diagnosis. It is expected that researchers would explore appropriate ways to reduce the speckle noise, to find the edges of structures and enhance weak borders between different organs in ultrasound imaging. Inspired by the principle of differential interference contrast microscopy, a "bas-relief map" is proposed that depicts the texture structure of ultrasound images. Based on a bas-relief map, an adaptive bas-relief filter was developed for ultrafast despeckling. Subsequently, an edge map was introduced to enhance the edges of images in real time. The holistic bas-relief map approach has been used experimentally with synthetic phantoms and digital ultrasound B-scan images of liver, kidney and gallbladder. Based on the visual inspection and the performance metrics of the despeckled images, it was found that the bas-relief map approach is capable of effectively reducing the speckle while significantly enhancing contrast and tissue boundaries for ultrasonic images, and its speckle reduction ability is comparable to that of Kuan, Lee and Frost filters. Meanwhile, the proposed technique could preserve more intra-region details compared with the popular speckle reducing anisotropic diffusion technique and more effectively enhance edges. In addition, the adaptive bas-relief filter was much less time consuming than the Kuan, Lee and Frost filter and speckle reducing anisotropic diffusion techniques. The bas-relief map strategy is effective for speckle reduction and live enhancement of ultrasound images, and can provide a valuable tool for clinical diagnosis. (E-mail: zhangjue@pku.edu.cn)

Key Words: **Ultrasound biomedical B-scan image, Texture analysis, Bas-relief filter, Speckle reduction, Edge enhancement, Canny edge detection, Field II simulation.**

INTRODUCTION

Ultrasound imaging is widely used in medical diagnosis because of its non-invasive nature, low cost, portability and real-time image formation. However, ultrasound imaging properties such as speckle cause the edges and borders on the images to be not as clear as expected by physicians. Therefore, finding appropriate ways to reduce speckle noise, to delineate the edges of structures and enhance weak borders between different organs, is an area of great interest for researchers in medical image processing.

To achieve enhancement, a number of competitive speckle reduction spatial domain filters have been developed with different levels of success over the past three decades (Contreras Ortiz et al. 2012). In the spatial domain, the median filter (Huang et al. 1979) and several of its adaptations can effectively suppress speckle, but generally fail to preserve many valuable details and even blur edges and tiny details. The classic Wiener filter (Wiener 1949), which uses second-order statistics of the Fourier decomposition, is not adequate for removing speckle because it was designed mainly for additive noise suppression. Adaptive spatial filtering techniques such as the Lee (1981) and Kuan (Kuan et al. 1987) filters adequately restore the heterogeneous pixel characteristics. Both filters achieve a balance between straightforward averaging (in homogeneous regions) and the identity filter (where edges and point features exist) which depends on the coefficient of variation inside the moving window. Also, the Frost filter (Frost et al. 1982) achieves balance by forming an exponentially shaped filter kernel that can vary from a basic average filter to an identity filter on a pointwise and adaptive basis; response

Address correspondence to: Jue Zhang, Peking University, No.5 Yiheyuan Road, Haidian District, Beijing, 100871, China. E-mail: zhangjue@pku.edu.cn

Table 1. 5 × 5 Laws masks (2-D kernels) used to perform texture analysis

Kernel name	Value using 1-D kernels	Description—features extracted from texture
L5E5	L5TE5	Edge detection in horizontal direction and gray-level intensity in vertical direction
E5L5	E5TL5	Gray-level intensity in horizontal direction and edge detection in vertical direction
L5S5	L5TS5	Spot detection in horizontal direction and gray-level intensity in vertical direction
S5L5	S5TL5	Gray-level intensity in horizontal direction and spot detection in vertical direction
E5E5	E5TE5	Edge detection in both vertical and horizontal directions

varies locally, more average-like with low coefficients of variation and not average-like in cases of high coefficients of variation. Those filters effectively suppress speckle without losing the valuable information present in the medical B-scan images. However, the existing filters do not enhance edges—they only inhibit smoothing near edges. Perona and Malik (1990) proposed the Perona–Malik anisotropic diffusion (PMAD) filter, and Yu and Acton (2002) developed a speckle reducing anisotropic diffusion (SRAD) filter; these filters emphasize edge enhancement rather than improved visualization.

Another challenge in ultrasound image enhancement is the enhancement of weak borders caused by steering beams because the beam line is not perpendicular to the orientation of the local edge (Wang and Liu 2008). Meanwhile, the boundaries of interest in an ultrasound image are discontinuities between tissue layers, which are large on the scales of both the wavelength of interrogation and scan line spacing. Conventional edge detection procedures, for example, Canny, Roberts or Sobel operators and related techniques (Bovik 1988), are not well modeled to catch such discontinuities. Thus, they do not adequately enhance the edges in ultrasound images.

Texture analysis is important in many applications (Tuceryan and Jain 1998) of computer image analysis for classification, synthesis, detection, segmentation and inferences about the 3-D shapes of images based on local spatial patterns of intensity or color, which provide the possibility of speckle suppression without affecting the important diagnostic features of the image.

In his well-known studies, Laws (1979, 1980a, 1980b) proposed a texture analysis using convolutions, a kind of correlation, with various feature masks representing local patterns. He empirically determined that several of these, of appropriate sizes, were very useful for discriminating among many kinds of texture.

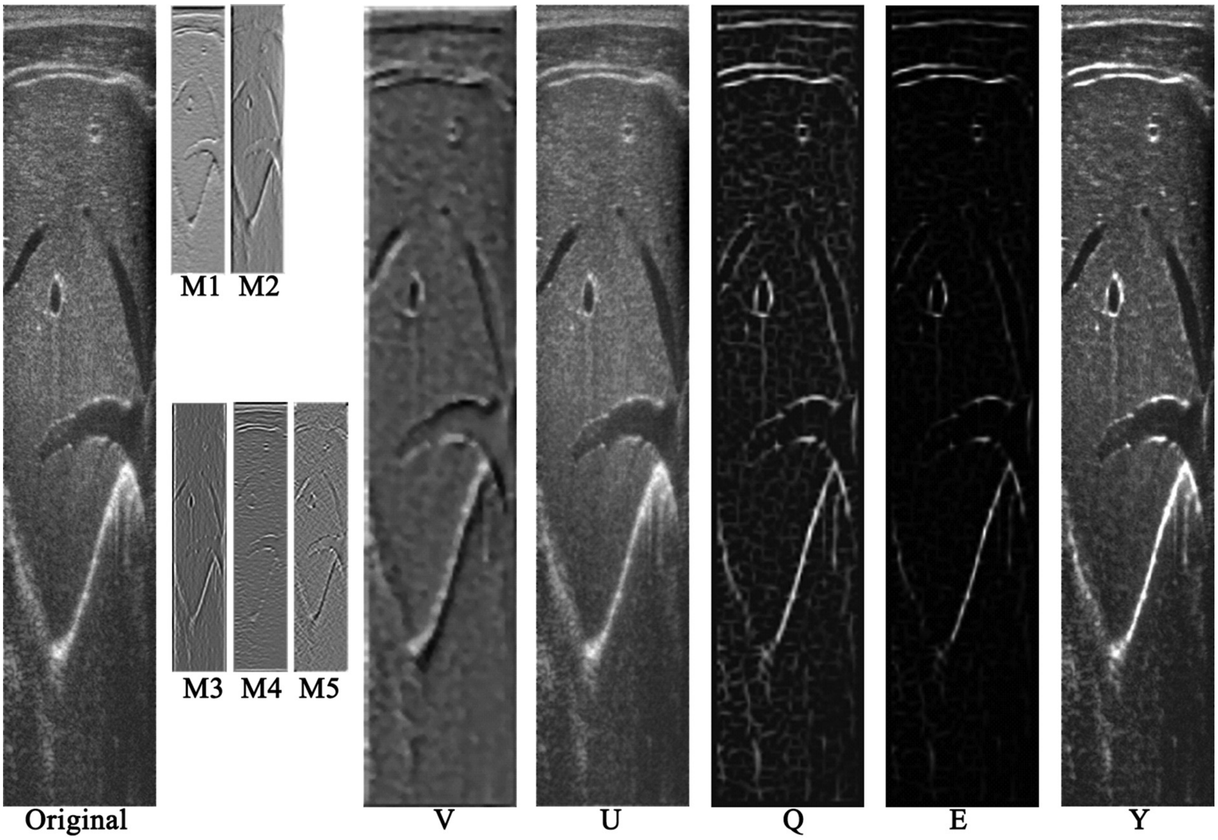

Fig. 1. Procedure for enhancement of an ultrasound image of liver with bas-relief map approach.