Quantum-inspired hybrid medical ultrasound images despeckling method

Xiaowei Fu, Yi Wang, Li Chen and Yun Dai

A novel medical ultrasound despeckling method combining quantum-inspired bilateral filtering and wavelet thresholding is proposed. An adaptive bilateral filter under the framework of quantum signal processing is exploited in this method and used as a pre-processing step. Then wavelet thresholding, on the assumption that the signal and noise coefficients in the wavelet domain are subject to generalised Laplace distribution and Gaussian distribution, respectively, is applied to the pre-filtered image. Experiments show that the proposed method can obtain a better speckle noise reduction performance while retaining high-contrast features such as edges.

Introduction: In medical diagnosis, ultrasonography has been considered as one of the most popular modalities of medical imaging systems. However, medical ultrasonographic images generally suffer from speckle noise, which results in poor visibility. Bilateral filtering is a simple nonlinear denoising method, which exploits both the geometric closeness and the photometric similarity of images [1]. It conquers the weakness of some early spatial adaptive filters, including the Frost filter, Lee filter, the Kuan filter and the fast Fourier transform domain denoising Wiener filter, which can only reduce noise without maintaining edge information very well [2]. Discrete wavelet transform (DWT) has been the trend for speckle removal. The non-log transformed generalised likelihood ratio based wavelet domain denoising method (GenLik) [3] is one of the most successful wavelet-based technologies with customisable parameters. Tian et al. [4] have proposed a non-parametric statistical model and created a maximum a posteriori (MAP) estimation-based image despeckling method. However, they still have limitations in preserving sharp edges. The dual-tree complex wavelet transform (DTCWT) has been proposed to conquer the weakness of DWT, such as the down-sampling operation and lack of providing phase information [5]. The quantum signal processing (QSP) framework is a new mechanism which introduces quantum mechanics into the signal processing field [6]. It focuses on the measurement, coherence and other concepts related to quantum mechanics to provide a broad application prospect. Many existing quantum-inspired approaches, including the quantum neural network, the quantum genetic algorithm and quantum-behaved particle swarm optimisation, have achieved great success in signal processing, data mining and artificial intelligence. This inspires exploration into the application of basic quantum theory in image processing technology. Considering the limitations of the current methods and combining the QSP framework with traditional image processing methods, Fu et al. [2] have proposed a quantum-inspired adaptive threshold function for medical ultrasound images despeckling and improved the despeckling and detail preserving performance.

The efficient application of bilateral filtering and wavelet in despeckling, and the introduction of the QSP framework into the image processing issue have become the motivations of the work reported in this Letter. In this Letter, a pre-processing step is conducted by bilateral filtering designed under the framework of QSP. The locality of an image is exploited by adapting the local entropy to design the weight used in the quantum-inspired weighted bilateral filter (QWBF). Then, wavelet thresholding is used for further suppression of speckle noise. Experimental results show that the proposed method can notably decrease speckle noise and simultaneously preserve sharp edges in medical ultrasound images.

Method: The bilateral filter is an efficient local denoising method, which can smooth images while preserving edges. It combines domain and range filtering and exploits the closeness and similarity of image pixels, which refer to the vicinity in the domain and range, respectively [7]. Traditional bilateral filter can be written as

$$I_{\tilde{l}}(x) = \frac{1}{N_{\text{window}}} \int_{x_{\text{domain}}} f_{\text{filter}}(x, y) f_{\text{filter}}(I(x), I(y)) \, dx \, dy$$

where $I_{\tilde{l}}$ denote the speckled image and the resulting image, respectively. $x$ is the filtered pixel. $N_{\text{window}}$ represents the window space of the neighbourhood region. The Gaussian function is used to express the filter, $f_{\text{filter}}(x, y)$ is the similarity function and is defined as

$$f_{\text{filter}}(x, y) = \exp \left( -\frac{||x - y||^2}{2\sigma^2} \right)$$

where $||x - y||$ is the Euclidean distance between $x$ and $y$. The standard deviation $\sigma$ should vary with the contamination level of the speckle noise. In consideration of maintaining the detail information while despeckling, two parts of the filtering results, $I_{\text{filter}}$ and $I_{\text{filter}}$, are computed by setting the value of $\sigma$, 5 and 20, respectively. Then an overall filtered image $\tilde{Y}$ is obtained by the proposed QWBF

$$\tilde{Y} = (1 - w) \cdot I_{\text{filter}} + w \cdot I_{\text{filter}}$$

where $w$ is a proposed quantum-inspired weight. By adapting the basic principle of QSP [6], the weight is a superposition state of the noise and the signal

$$w = a |0\rangle + b |1\rangle$$

where noise $|0\rangle$ and signal $|1\rangle$ are ground states in the QSP framework, $a$ and $b$ are probability amplitudes of the ground states $|0\rangle$ and $|1\rangle$, respectively. The value of $|\psi^*|^2$ can be used to describe the probability of the appearance of noise, which is designed as

$$w = \sin^2(\psi \theta \times \pi/2)$$

$w_{|\psi \rangle}$ is related to the locality of the image. It is designed using image local entropy, which reflects the amount of information in the image. $w_{|\psi \rangle}(x, y)$ is the value at pixel $x$ related to neighbour $y$, and is defined as

$$w_{|\psi \rangle}(x, y) = \frac{F(x) - l}{\max(F) - l}$$

where $F(x)$ represents the local entropy of the $9 \times 9$ neighbourhood around the corresponding pixel $x \in \xi$ is an adjustable value computed by averaging the 5th to 20th rows of $F$.

The QWBF is focused on the locality and adaptivity to provide better pre-filtering performance. Then a wavelet thresholding process is conducted to suppress speckle noise. In the DTCWT domain, the log-transformed ultrasound image can be modelled as $Y = X + N$, where $Y = Y_1 + Y_2$, $X = X_1 + iX_2$ and $N = N_1 + iN_2$ are the complex wavelet coefficients of the speckled image, the noise-free image and the random speckle noise, respectively. The MAP estimator is used to recover the noise-free wavelet coefficients $X$ via noisy sample $Y$. The distribution of log-transformed speckle noise is close to a Gaussian probability density function [8]

$$p_Y(N) = \frac{1}{2\sigma_Y^2} \exp \left( -\frac{N_1^2 + N_2^2}{2\sigma_Y^2} \right)$$

where $\sigma_Y$ is the standard deviation of the noise, which is robustly estimated as $\sigma_Y = \text{median}(|Y^{45\circ}|)/0.6745$, where $|Y^{45\circ}|$ denotes the modulus of the wavelet coefficients in the $45^\circ$ direction subband at the finest scale. The distribution of the log-transformed image signal is defined as a non-Gaussian statistical model

$$p_X(X) = \frac{3}{2\sigma_X^2} \exp \left( -\frac{\sqrt{3}}{\sigma_X} \sqrt{X_1^2 + X_2^2} \right)$$

where $\sigma_X$ is the standard deviation and is estimated by the maximum likelihood estimator [9]. The estimator is presented as

$$\hat{X} = \arg \max p(X|Y)$$
According to Bayes’ theorem, the MAP estimator of $X$ can be derived as

$$
\hat{X} = \frac{\sqrt{y_1^2 + y_2^2} - \sqrt{3}y_2/\sigma_0}{\sqrt{y_1^2 + y_2^2}} \times Y
$$

(12)

where the noisy wavelet coefficient $y_2$ is the parent of $y_1$.

The proposed algorithm is summarised as follows

1. Take a log-transformation to obtain $I$.
2. Conduct QWBF using (5) to obtain the pre-filtered $\tilde{Y}$.
3. Decompose $\tilde{Y}$ by DTCWT and estimate wavelet coefficients $\hat{X}$ using (12).
4. Apply the inverse DTCWT to the estimated coefficients.
5. Take an exponential-transformation to obtain the despeckled image.

**Experimental results:** The proposed method is compared with the Frost filter, the log-wavelet BI-DTCWT denoising method, the Wiener filter and the homomorphic Wiener filter and the existing quantum-inspired method. The speckle noise simulation method refers to [2]. All the experiments were conducted using the MATLAB programming environment on a 2.90 GHz Intel Pentium G2020 PC. Fig. 1 shows the visual quality of the experiments. Table 1 gives the objective evaluation of Fig. 1. The signal-to-noise ratio (SNR), the edge preservation measurement and the structural similarity index measure (SSIM) [10] are used to objectively evaluate the despeckling results of the compared methods. As can be observed, the proposed method not only gives superior performance in terms of objective evaluation, but also has a better subjective image quality.

![Fig. 1 Medical ultrasound image despeckling experiments](image)

- a: Original image
- b: Speckled image with standard deviation of 0.9
- c: Result by Frost filter
- d: Result by log-wavelet BI-DTCWT method
- e: Result by Wiener filter
- f: Result by homomorphic Wiener filter
- g: Result by quantum-inspired DTCWT method
- h: Result by proposed method

**Table 1:** Objective evaluation of Fig. 1

<table>
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<tr>
<th>Method</th>
<th>SNR</th>
<th>β</th>
<th>SSIM</th>
</tr>
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<tbody>
<tr>
<td>Speckled</td>
<td>9.64</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>Frost</td>
<td>13.83</td>
<td>0.31</td>
<td>0.77</td>
</tr>
<tr>
<td>BI-DTCWT</td>
<td>11.91</td>
<td>0.29</td>
<td>0.69</td>
</tr>
<tr>
<td>QSP</td>
<td>15.10</td>
<td>0.52</td>
<td>0.82</td>
</tr>
<tr>
<td>Wiener</td>
<td>13.55</td>
<td>0.25</td>
<td>0.79</td>
</tr>
<tr>
<td>Hom-Wiener</td>
<td>16.12</td>
<td>0.47</td>
<td>0.85</td>
</tr>
<tr>
<td>This work</td>
<td>16.75</td>
<td></td>
<td>0.88</td>
</tr>
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**Conclusion:** An effective quantum-inspired despeckling method has been proposed for medical ultrasound images. The use of novel quantum-inspired bilateral filtering as a pre-processing provides better overall despeckling performance. Furthermore, the proposed QWBF, which investigates the local entropy of the image with the quantum inspired theory, provides new ways to solve medical images processing problems. Experimental results using real medical images demonstrate that the proposed method has a competitive performance in suppressing speckle noise and preserving details for medical ultrasound images.

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**References**


