Reduction of noise in electron holography by using dual-tree complex wavelet transform and hidden Markov tree models

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Electron holography is used to observe the nanometer-scale electro-magnetic field distribution of electronic and magnetic materials [1]. A coherent electron wave emitted from the electron source propagates into a sample. Half of the wave passes through the sample (object wave), and the other half passes through a vacuum area (reference wave). The object and reference waves are superimposed by using a biprism filament under the object plane and then an interference fringe pattern is generated. The electromagnetic field is visualized by detecting the phase shifts of the fringe pattern. It is necessary to reduce noise in electron hologram in order to measure a minute phase change accurately.

In this work, we try to reduce noise in electron holography by using dual-tree complex wavelet transform (DTCWT) and hidden Markov models (HMM). DTCWT is a discrete wavelet transform (DWT) using two pairs of scaling functions and wavelets corresponding to the real part and the imaginary part [2]. As shown in figure 1, DTCWT has shift invariance and high direction selectivity (6 subbands: +15, +45, +75, -15, -45, -75 degrees) compared with DWT. A hidden Markov tree model is constructed for each of 6 subbands. Each pixel is labeled by a hidden state signifying whether the wavelet coefficient is small or large, and then the variance of the wavelet coefficient is predicted based on the hidden state and the state transition probabilities between wavelet levels. The denoised image is obtained by suppressing wavelet coefficients considering the estimated variance and then by performing the inverse DTCWT.

We evaluated the noise reduction effect through simulated electron holograms. Simulated hologram with noise (H_n) is obtained by adding Gaussian noise to the hologram with no noise (H_0). Gaussian noise at each pixel in H_n is generated with the mean and the variance that are equal to the gray value at the corresponding pixel in H_0. Figure 2(a) shows simulated holograms H_0 and H_n, and holograms obtained by DWT-HMM (wavelet: Daubechies8) and DTCWT-HMM (wavelet: Farras and Kingsbury Q-shift), respectively. Figure 2(b) shows the reconstructed phase images obtained from the above holograms (figure 2(a)) by the Fourier transform method, respectively. Figure 2(c) shows the unwrapped phase images obtained from the above phase images (figure 2(b)), respectively. From these results, it is seen that the unwrapped image for DTCWT-HMM is close to that for H_0. Quantitatively, the mean absolute phase errors are reduced from 2.39 [rad] of H_n to 1.13 and 0.4 [rad] by applying DWT-HMM and DTCWT-HMM, respectively.

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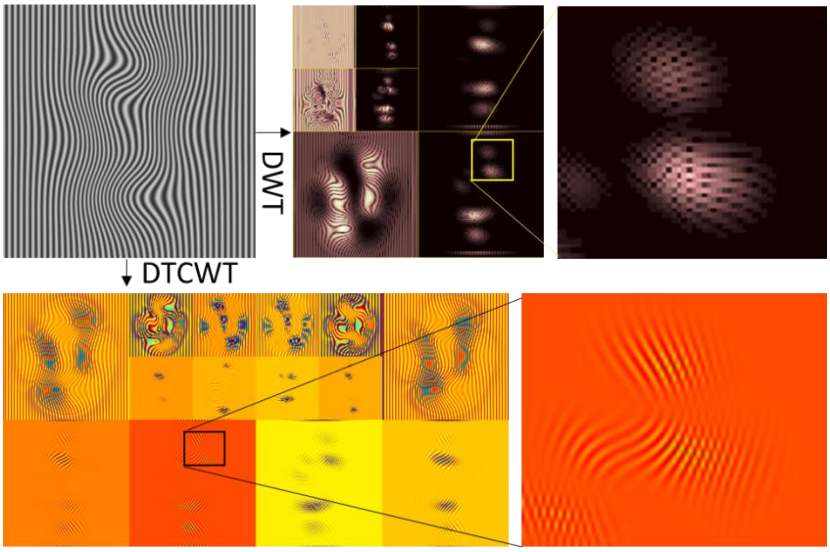

Fig. 1: Wavelet decompositions when using DWT and DTCWT where the simulated hologram with no noise (H_0) is used.

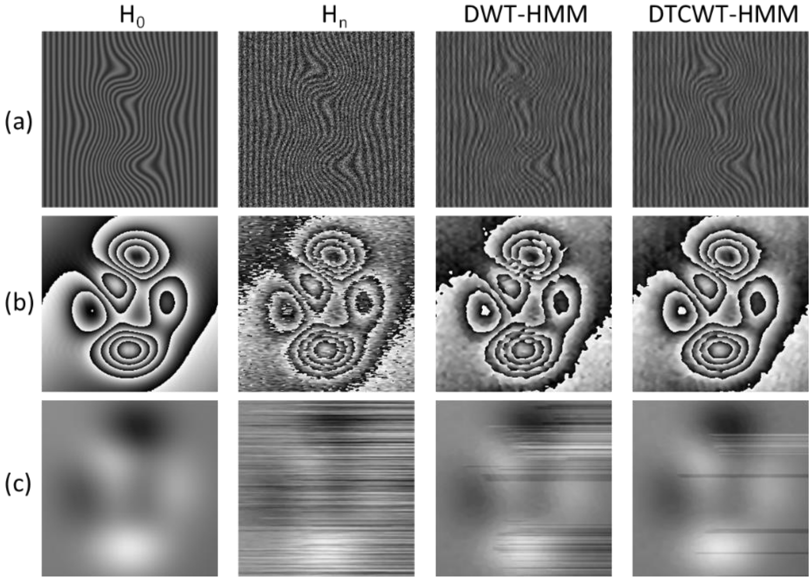

Fig. 2: Applied results: (a) holograms, (b) reconstructed phase images, and (c) unwrapped phase images.