Restoration of phase data with high noise and dislocations by combining filtering, masking, unwrapping and inpainting

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Abstract: A robust approach to restore phase data with high noise and dislocations is proposed based on combining filtering, masking, unwrapping and inpainting. Simulations and experimental results demonstrate the proposed approach is robust and fast. © 2019 The Author(s)

OCIS codes: (090.1995) Digital holography, (100.5088) Phase unwrapping, (120.5050) Phase measurement, (110.4280) Noise in imaging systems, (100.3020) Image reconstruction-restoration, (100.2980) Image enhancement.

1. Introduction

For the most complicated phase maps with both high noise and dislocations, the processing approach to be applied has to be established. Particularly, operations based on de-noising, unwrapping and in-painting must be used for such phases. In this paper, we proposed a robust restoration approach for phase data with high noise and dislocations based on combined de-noising, masking, unwrapping and inpainting. The proposed approach is validated and compared with other restoration approaches by realistic numerical simulations. The applicability of the proposed approach was demonstrated through application to deformation measurement in dental materials.

2. Proposed phase processing approach

The proposed approach includes four processes: first, de-noising with the windowed Fourier transform algorithm WFTF [1], second, detecting and masking out of dislocations with second order phase gradients [2], third, unwrapping with PULSI [3], and finally, inpainting by interpolation [2]; this is referred as WFTF+MASK+PULSI+INTERP (or WMPI) in the following.

3. Evaluation of the proposed approach

In order to evaluate the robustness of the proposed approach, five other combinations were selected: 1. first, de-noising with WFTF, second, detecting and masking out of dislocations with second order phase gradients, third, inpainting by exemplar based algorithm [4], and finally, unwrapping with PULSI; this is referred as WFTF+MASK+EB+PULSI (or WMEP); 2. first, detecting and masking out of dislocations with second order phase gradients, second, unwrapping with CPULSI[5], third, de-noising with median filter [6], and finally, inpainting by interpolation; this is referred as MASK+CPULSI+MEDFILT+INTERP (or MCMI); 3. first, detecting and masking out of dislocations with second order phase gradients, second, unwrapping with CPULSI, third, inpainting by interpolation, and finally, de-noising with median filter; this is referred to as MASK+CPULSI+INTERP+MEDFILT (or MCIM); 4. first, detecting and masking out of dislocations with second order phase gradients, second, inpainting by exemplar based algorithm, third, unwrapping with CPULSI, and finally, de-noising with median filter; this is referred as MASK+EB+CPULSI+ MEDFILT (or MECM); 5. first, detecting and masking out of dislocations with second order phase gradients, second, inpainting by exemplar based algorithm, third, de-noising with WFTF, and finally, unwrapping with PULSI; this is referred to as MASK+EB+WFTF+PULSI (or MEWP).

In order to evaluate the robustness of the proposed approach, realistic numerical simulations [7] of phase data with speckle decorrelation noise and dislocations were carried out. In the simulator, the noise level is controlled by the fringe density when increasing the amplitude of the unwrapped phase. Ten phase maps were simulated by increasing the amplitude in the fringe phase pattern. Figure 1(a) shows sets of phase maps with high noise and phase dislocation (indicated by the red circle). The proposed WMPI and five approaches mentioned above were applied to restore the simulated phase maps. In order to get a quantitative evaluation of the errors from the phase restorations, the standard deviations of the phase errors were evaluated. Figure 1(b) provides the standard deviation of the phase error according to the standard deviation of the noisy phase. The computational cost of the different combinations was evaluated and compared (see Fig. 1(c)). These results demonstrate that WMPI has the best accuracy and the fastest computation speed compared to other approaches.

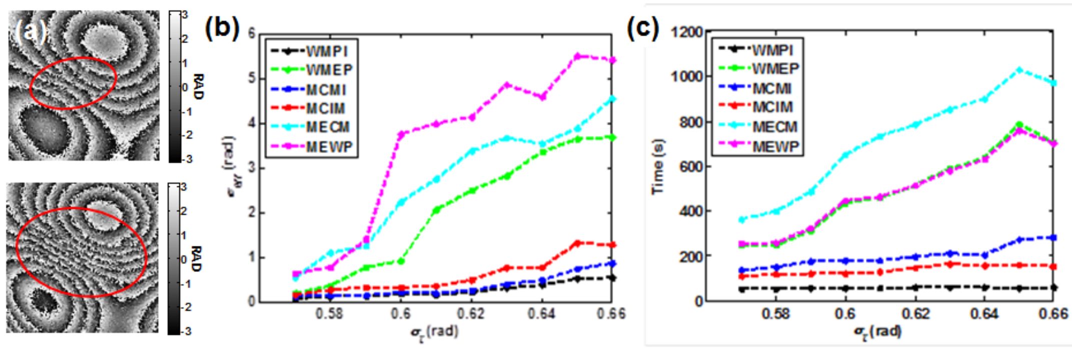

Fig.1. (a) Noisy phases with dislocations (red circles), (b) standard deviations of the restored phase errors, (c) computation times of the different combinations.

4. Application in experimental phase data

The practicability of the WMPI was used to recover an experimental phase map obtained from color digital holography [8]. Figure 2(a) shows a photograph of the tooth sample, and Fig. 2(b) to Fig. 2(e) provide phase maps from the different steps of WMPI. Figure 2(f) yields the final restored phase map. From this application can be seen that WMPI can successfully recover the practical phase data with high noise and dislocations.

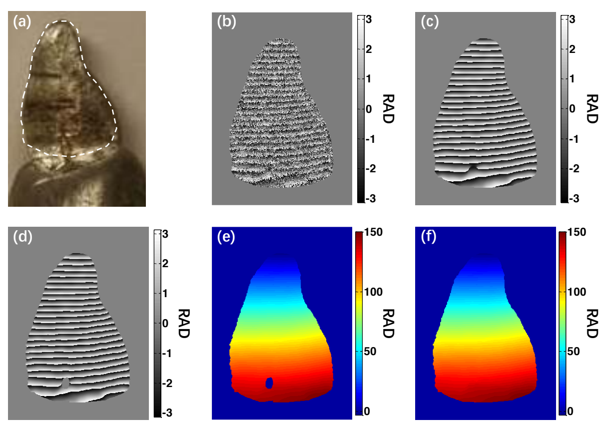

Fig. 2. Restoration of experimental phase data with WMPI, (a) tooth specimen, (b) wrapped phase with high noise and dislocation, (c) de-noised wrapped phase, (d) wrapped phase masked dislocation, (e) unwrapped phase and (f) final restored phase.

5. Conclusions

This paper proposes a fast and robust approach to deal with phase map high corrupted by noise and dislocations. Experimental results validate the feasibility and practicability of the proposed approach. This work was supported by the Natural Science Foundation of China (11862008, 11462009).

6. References

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