Filtering Fringe Patterns with the Extended Non Local Means Algorithm

Maciej Wielgus and Krzysztof Patorski
Institute of Micromechanics and Photonics, ul. Św. A. Boboli 8, 02-525 Warsaw, Poland

Keywords: Fringe Pattern Processing, Image Filtration, Non Local Means.

Abstract: The quality of interferometric measurements substantially benefits from the digital noise filtration. Recently, robust non local filtration algorithms were introduced to optical metrology, the non local means algorithm in particular. These methods allow to take advantage from the information redundancy spread in the whole image domain for processing each pixel, constituting a powerful image denoising tool. We evaluate how the denoising performance quality of the non local means algorithm can be further increased by the introduction of geometrical transformations of the compared patches.

1 INTRODUCTION

Uncertainty is an intrinsic feature of every measurement, appearing as noise in the measuring system output. For fundamental reasons it is impossible to fully remove its influence by hardware setup modification. Instead of increasing the hardware requirements most (if not all) systems for interferometric measurements introduce some digital noise filtration, applied to the registered pattern before further processing. In many cases this is a simple down-pass filtration by averaging with binary or Gaussian mask. Median filter is a popular choice as well. Dozens of more sophisticated methods were proposed throughout the years.

One of the attractive novel developments in image processing is the notion of the non local filtration such as the non local means algorithm – NLM (Buades et al., 2005). This group of methods was recognized in the fringe pattern analysis just recently. In (Wielgus and Patorski, 2012) basic NLM algorithm was tested against several popular filtration methods for interferometric pattern filtration, while in (Fu and Zhang, 2012) modified technique was proposed. The power of non local methods lays in their ability of utilizing redundancy in the whole image domain rather than in limited neighbourhood of the considered pixel. Typically in non local processing we compare patches (small subimages containing the central pixel and its neighbourhood) and average the intensities of their central pixels based on established measure of patch similarity. Unlike local averaging, the non local method enables to avoid oversmoothing the image and blurring its delicate features.

Robustness of non-local filtration for photographic images, as shown in (Buades et al., 2012), could be found as a surprising issue, as these images do not represent any visible similarity of distant patches. However, as noted in (Wielgus and Patorski, 2012), situation is very different with fringe patterns, which are quasiperiodic in nature and therefore display similarity even between significantly distant patches. To illustrate and quantitatively evaluate this effect we calculate the correlation of the fringe pattern presented in Figure 1 (a) with its chosen patch, located in the centre of the image. This is a fragment of an experimentally obtained interferogram of a silicone micromembrane (Salbut et al., 2003). In Figure 1 (b) we show the map of cross-correlation between the image and the selected patch (brighter color = more similarity). Note that it is a nonmonotonic function of distance from the considered patch and that correlation reaches high values even quite far away from the chosen patch. This explains why non local methods are supposed to fit particularly well for the fringe pattern filtration. For the sake of clarity, only pixels with normalized correlation larger than 0.3 are shown.

In this paper we intend to exploit another property of fringe patterns to further increase the redundancy from which non local methods benefit,

Wielgus M. and Patorski K..
Filtering Fringe Patterns with the Extended Non Local Means Algorithm.
DOI: 10.5220/0004339500520055
In *Proceedings of the International Conference on Photonics, Optics and Laser Technology* (PHOTOPTICS-2013), pages 52-55
ISBN: 978-989-8565-44-0

namely the similarity under the geometrical operations of symmetry and rotation. In Figure 1 (c) correlation map for the very same patch as in Figure 1 (a-b) is shown for the case of allowing the comparison between rotated and mirrored patches. Clearly, there are many more patches that can be possibly used for the filtration and therefore more redundancy can be utilized. It can be quantitatively expressed in terms of the norm of correlation maps, which is 2.18 times larger for the map of Figure 1(c) than for the map presented in Figure 1 (b).

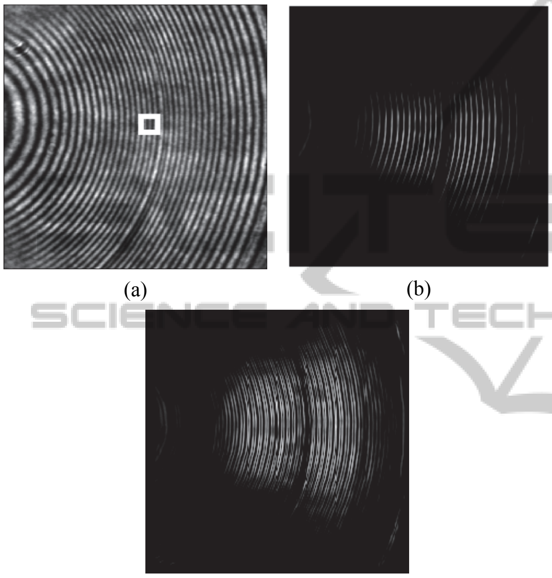


Figure 1: Fringe pattern with indicated chosen patch (a), correlation map of the pattern and the patch (b), correlation map of the pattern and the patch with geometric transformations allowed (c).

2 NLM ALGORITHM

The non local means algorithm (Buades et al., 2005) can be considered as a basic method for the non local patch-based filtration. It estimates the value of image intensity I^E in pixel k as a weighted average of intensities I in other pixels

$$I^E(k) = \sum_{m\in\Omega} w(k,m) I(m) \qquad (1)$$

where weights are specified based on similarities of the corresponding patches P_k and P_m

$$w(k,m) = \frac{1}{N(k)} \exp\left(-\frac{||I(P_k)-I(P_m)||_\sigma^2}{h^2}\right) \qquad (2)$$

$||\,.\,||^2_\sigma$ denotes Gaussian-averaged Euclidean distance between patches, h is the characteristic parameter of the algorithm. Normalization factor N(k) is simply

$$N(k) = \sum_{m\in\Omega} \exp\left(-\frac{||I(P_k)-I(P_m)||_\sigma^2}{h^2}\right) \qquad (3)$$

The choice of the negative exponential function of squared distance between patches is not unique, as any smooth function monotonically decreasing for positive arguments and reaching 0 at $+\infty$ could be used. It is important to emphasize that distance between pixels have no influence on weights, which is exactly what is meant by algorithm non-locality. Nevertheless, in any useful implementation, patches are compared only in certain regions limited by the distance from considered patch. The only reason for such limitation is the reduction of the computational load.

3 GEOMETRIC TRANSFORMATIONS

Proposed extension to the basic NLM algorithm lays in consideration of not only similarities between patches, but between mirrored and rotated patches as well. Such an extension is very well motivated for the fringe pattern filtration as cosine is not only periodic, but also symmetric function as well since orientation of fringes may strongly vary for different pixel locations. In total, we consider 6 distinct transformed patches $I^{(n)}(P_k)$, n = 1, 2, ..., 6:

- initial one,
- 3 rotations (90, 180 and 270 degrees),
- 2 symmetries (with respect to the horizontal and vertical axis).

We calculate the weights similarly as in (2), only for each pair of patches P_k and P_m we choose the best weight from 6 transformations

$$w(k,m) = \max_n \frac{\exp\left(-||I^{(n)}(P_k)-I(P_m)||_\sigma^2/h^2\right)}{N(k)} \qquad (4)$$

In this manner we are capable of recognizing and utilizing for denoising purposes the pixels that are very similar but lay in the rotated (different fringe orientation) or mirrored (different side of the fringe) neighborhoods. Information gain was presented in Figure 1.

4 NUMERICAL EXPERIMENTS

In the following experiment we compare filtration results obtained by Gaussian smoothing, median filtration, and more sophisticated anisotropic diffusion filter based on (Tang et al., 2008), classic NLM algorithm and finally our extended NLM algorithm. We demonstrate the algorithm performance on the synthetic pattern of vertical fringes with slight phase distortion, spoiled with additive white Gaussian noise (signal to noise ratio smaller than 2), Figure 2 (b). Knowing the original pattern (one without the noise, Figure 2 (a)), we are able to quantitatively evaluate the denoising performance in terms of the root mean square error (the difference between fringe pattern without any noise imposed and the filtration result), which is summarized in the Table 1. We also include the full processing error evaluation, which is the root mean square error of the Fourier method based phase calculation performed on the denoised image.

Table 1: Filtration quality evaluation for the synthetic pattern.

Algorith m	Denoising RMSE	Noise reduction [%]	Phase RMSE
No filtration	64.20	0	50.42
median	34.64	46.0	26.10
Gaussian	28.84	55.1	19.82
Tang	23.20	63.9	17.95
NLM	20.16	68.6	16.23
Extended NLM	18.57	71.1	15.48

The significant drawback of many simple filtration algorithms is oversmoothing in the regions of considerable fringe deformations or pattern discontinuities, e.g., in the region of a sudden change in the specimen height. In Fig. 4 we show the denoising result of the extended NLM algorithm for the case of synthetic data with fringe discontinuity to indicate the algorithm satisfactory behavior in such a region.

In Figure 4 the results of denoising the real interferogram, shown in Fig. 1 (a), are presented. Once again, high quality of the extended NLM denoising is observable.

No fine tuning of the algorithms parameters was done. The extended NLM method has shown abilities to perform high quality fringe pattern denoising.

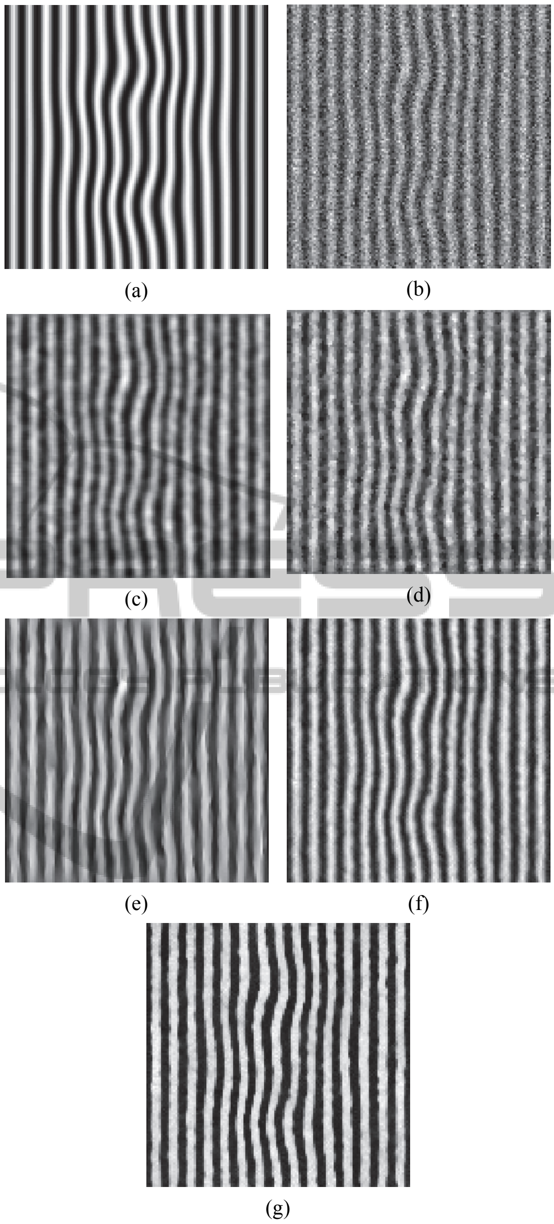
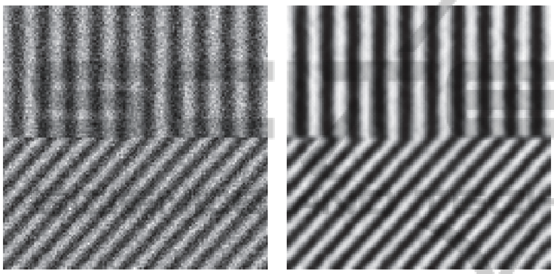


Figure 2: Synthetic interferogram (a), interferogram with added noise (b), result of Gaussian denoising (c), median filter denoising (d), (Tang et al., 2008) (e), the regular NLM algorithm (f), and the extended NLM (g).

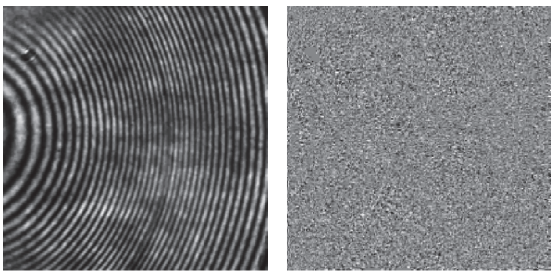
5 CONCLUSIONS

We showed how a simple extension of the non local means algorithm, namely the consideration of geometrically transformed patches, can increase the fringe pattern filtration quality. The denoising procedure quality have strong influence on the performance of further processing, such as phase decoding and therefore impacts on the quality and sensitivity of the whole measurement process. One could imagine extension of this method to any arbitrary angle, which would vastly increase redundancy in case of non-uniform, smoothly varying fringe orientation angle. However, this would as well further increase already rather high numerical cost of computations. In fact, this seems to be the main disadvantage and limitation of the non-local filtration methods. The situation is expected to change in the forthcoming years with further growth of computer computational power as well as with increasing popularity of computations on parallel architecture, which is highly suitable for the non local filtration implementations.



(a) (b)

Figure 3: Performance of the extended NLM method in the fringe discontinuity region. The pattern (a) and the denoising result (b).



(a) (b)

Figure 4: Denoised real interferogram (a) and difference between the original and denoised images (b).

ACKNOWLEDGEMENTS

This research was supported by the fundings of the Faculty of Mechatronics, Warsaw University of Technology.

REFERENCES

Buades, A., Coll, B., Morel, J. M., 2005. A review of image denoising algorithms, with a new one. *Multiscale Model. Simul. 4(2) 490-530.*

Wielgus, M., Patorski, K., 2012. Non-local fringe image filtration: a new interferometric data filtration paradigm? *Photonics Letters of Poland 4(2) 66-68.*

Fu, S., Zhang, C., 2012. Fringe pattern denoising using averaging based on non-local similarity. *Optics Communications 285 2541-2544.*

Salbut, L., Patorski, K., Jozwik, M., Kacperski, J., Gorecki, C., Jacobelli, A., Dean, T., 2003. Active micro-elements testing by interferometry using time-average and quasi-stroboscopic techniques. *Proc. SPIE 5145, 23–32.*

Tang, C., Han, L. Ren, H.., Zhou, D., Chang, Y., Wang., X., Cui, X., 2008. Second-order oriented partial-differential equations for denoising in electronic-speckle-pattern interferometry fringes. *Optics Letters, Vol. 33. No. 19, 2179-2181.*