TECHNIQUES FOR AUTOMATIC IDENTIFICATION AND NUMBERING OF INTERFERENCE FRINGES USING MATLAB

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1. Introduction

The *fringe skeletonizing technique* [1-5] for the evaluation of interference fields is based on the assumption that the local extrema of the intensity distribution in the interferogram correspond to the extrema of the assumed harmonic function of the detected interference signal. In this case the phase difference of the interference field at pixels, where an intensity maximum or minimum is located, equals an even or odd integer multiple of π. Present automatic techniques for identification of these intensity extrema, i.e. identification of fringe centres, are computerized forms of manual or semi-automatic evaluation techniques, where the fringe centres were determined manually or using digitizing tablets [6]. The main problem in the presented technique is to determine points lying on fringe centres. In these points the phase difference is known.

A general process for evaluation of digitally recorded interferograms using the fringe skeletonizing method consists of the following steps:

A. **Digital recording of the interference pattern**
B. **Specification of the boundary of the area to be analyzed**
C. **Preprocessing of the interferogram**
D. **Identification of interference fringe centres**
E. **Numbering of interference fringes by interference order numbers**
F. **Reconstruction of phase values using techniques of interpolation** [4,6,7]

In this article we focus only on the problems of automatic identification and numbering of interference fringes. There exist many techniques for less or more effective solving of these problems. The possible approaches can be divided into those based on fringe tracing, those based on segmentation of the digital image and those falling not directly in one of these two categories.

2. Localization of fringe centers

Methods of segmentation of the interference pattern are based on separation of the whole digital image (interferogram) into several subareas representing dark or bright interference fringes using the gradient of the intensity distribution. It is possible to use methods of adaptive thresholding, binarization of the digital image and subsequent skeletonization of the binary image [8]. For most of interference patterns it is very difficult to determine a proper level of thresholding to ensure obtaining good and reliable results. For identification of different regions in the interferogram (valleys, ridges and slopes of the grayscale distribution) it is possible to use gradient operators for the edge detection in image processing analysis.

Fig.1 shows an example of the adaptive thresholding technique applied to the interference pattern with the nonuniform background intensity. The threshold is chosen on the basis of the analysis of the mean intensity in the recorded interferogram.

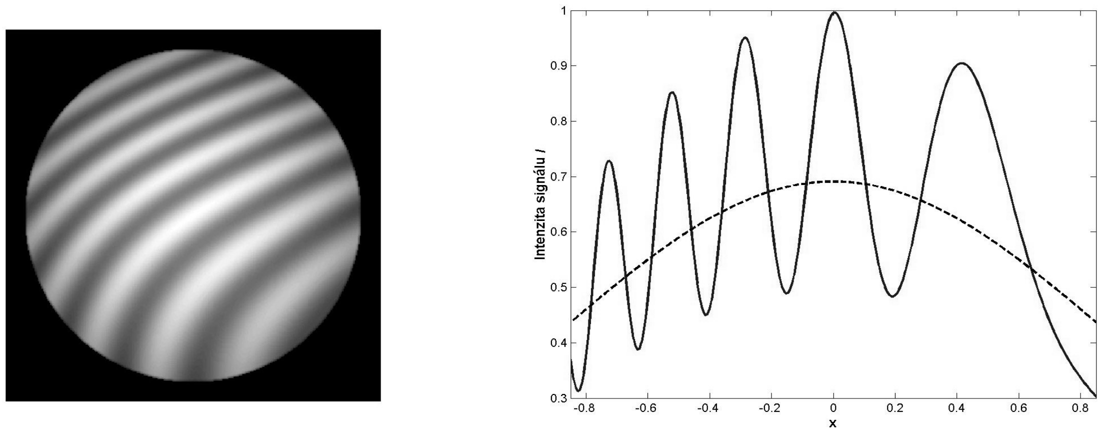

Fig.1: Interferogram with the cross-section of the interference pattern

The process of thresholding of the digital image can be mathematicaly described by the following expressions

$$I(x,y) < T \quad \Rightarrow \quad O(x,y) = 1\,, \tag{1a}$$

$$I(x,y) \geq T \quad \Rightarrow \quad O(x,y) = 0\,, \tag{1b}$$

where $I(x,y)$ is the original value of the intensity in the point (x,y) of the digitized interferogram, $O(x,y)$ is the resulting binary image and $T{=}T(x,y,p(x,y),I(x,y))$ is the threshold value in point (x,y) which depends on the grayscale value and properly chosen local properties $p(x,y)$ of the original image $I(x,y)$. On the basis of the chosen threshold the final binary image was obtained from the interference pattern in figure 1.

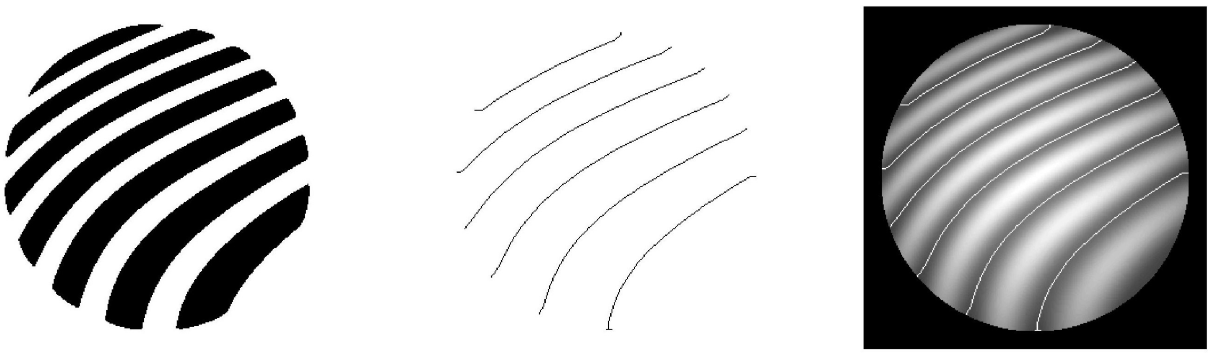

Fig.2: Segmentation of the interference pattern

This binary image of the interference pattern must be then skeletonized using binary morphological procedures (thinning) [8] to obtain fringe centres (**Fig.2**).

Another approach to identification of local extrema in interference patterns is based on evaluation of local properties of the small neighbourhood around the investigated pixel in the interferogram. This technique can be performed using special matrix operators with the size NxN pixels, where the size of the window N is usually chosen 3,5 or 7 with respect to spatial frequency of interference fringes. The matrix operator searches the local extrema of the interference pattern in four (or eight) different directions (x,y,xy,yx) comparing grayscale values in the local neighbourhood of the investigated pixel in the digital image. The mentioned procedure can be expressed as

$$I_O = I * L\,, \tag{2}$$

where I_O and I are output and input image data and the operator L is used as a convolution kernel. In **fig.3** there is shown the structure of this operator which looks for intensity extrema in four directions.

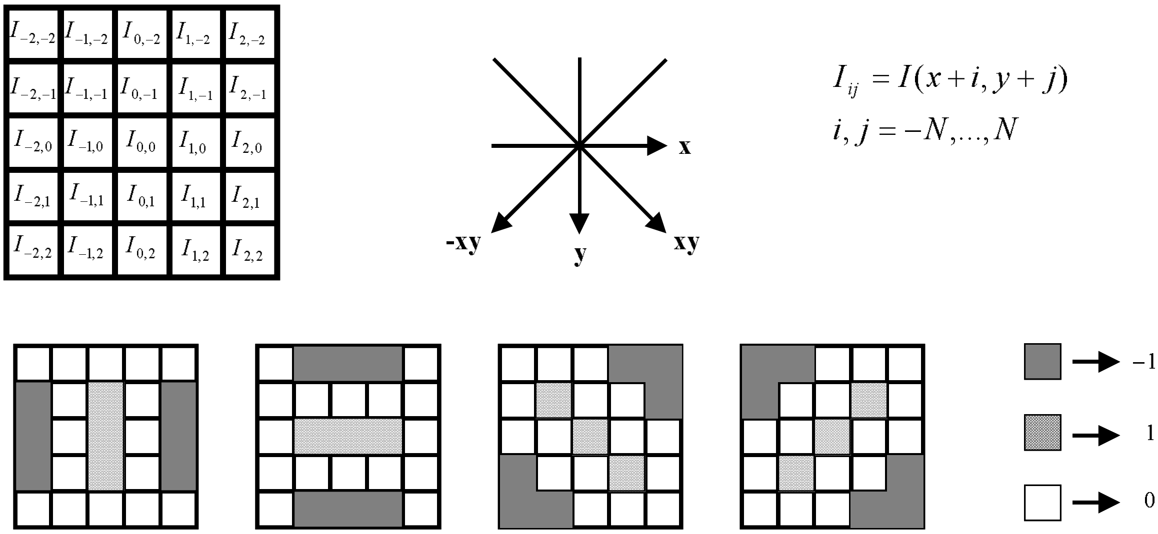

Fig.3: Scheme of the operator for an automatic identification of fringe centres

After using the described operator we obtain a raw skeleton image, i.e. several pixels thick fringes. This raw skeleton must be then thinned using some of binary morphological techniques (thinning and enhancing of fringe skeletons) and we obtain the final skeleton lines, i.e. one pixel wide interference fringes. (**Fig.4**).

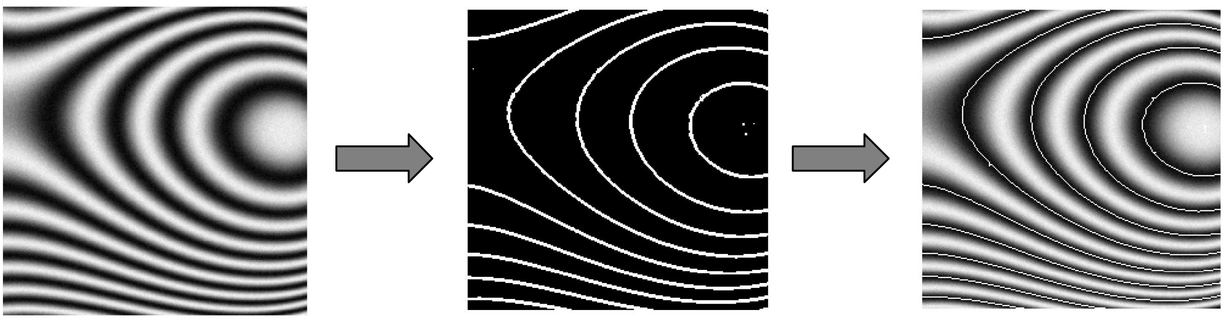

Fig.4: Process of automatic identification of fringe centres

The mentioned method for the automatic identification of interference fringe centres is more sensitive to the influence of the noise in the interference signal than the techniques which use segmentation of the interference pattern. But it offers a better resolution of fringe centres.

However, a correct reconstruction of phase values from interference fringes that are obtained with some of preceding methods is not a simple and unambiguous problem due to the previous evaluation process of the interference pattern.

3. Numbering of interference fringes

The next step in the evaluation process is unambiguous numbering of interference fringes (skeleton lines), i.e. defining a fringe order to each skeleton line. This step of the interferogram analysis is very important, because wrong numbering may cause large errors during the approximation of phase values. From a detail analysis of the interference patterns we can obtain several rules for fringe numbering that are valid in case of a continuous distribution of phase values:

- numbers of neighbouring skeleton lines may differ in fringe order only by –1, 0, or 1
- two skeleton lines with different fringe orders must not intersect or merge
- open skeleton lines must end at the border of the analyzed area
- sum of fringe order differences along any closed path through the interference pattern always yields zero

Nevertheless, the previous rules are not sufficient to ensure an unambiguous numbering of interference fringes, especially in case of nonmonotonous changes of phase values. Automatic fringe numbering algorithms based on these constraints still may require manual interaction. In this work there was proposed a technique for automatic numbering of interference fringes in case of open and closed fringes and this algorithm was implemented in Matlab. In **fig.5** and **fig.6** there are shown two examples of numbering of the interference patterns with different structure of interference fringes.

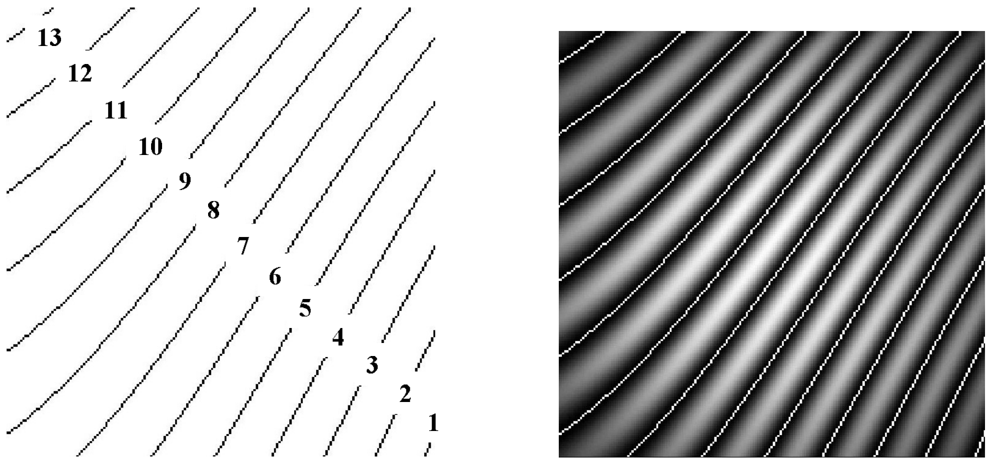

Fig.5: Process of numbering of interference fringes (open fringes)

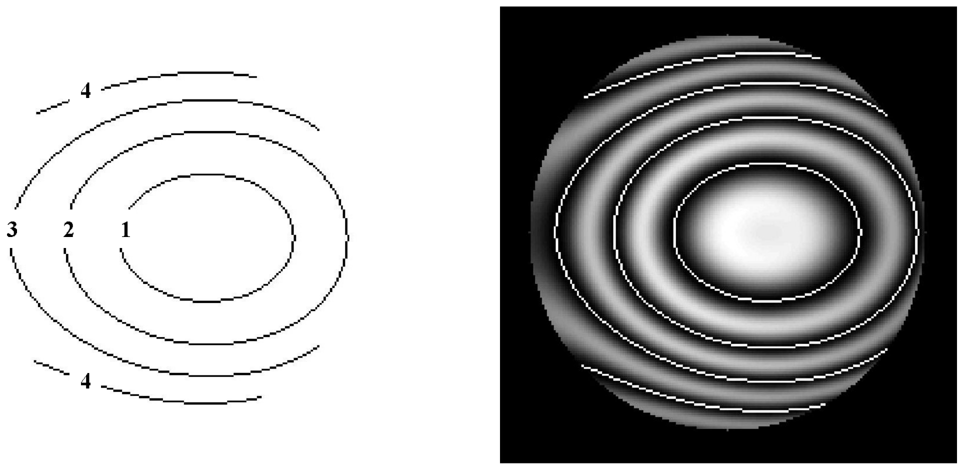

Fig.6: Process of numbering of interference fringes (closed fringes)

The process of numbering of skeleton lines is different for closed and open interference fringes and can be described by following steps:

- selection of the initial fringe and the choice of the fringe order, i.e. relative interference order (e.g. it can be chosen 0),
- choice of the direction of fringe numbering,
- considering mentioned rules for numbering of interference fringes and the border of area of interest.

If the phase distribution is continuous, then it is possible to divide the interferogram into several regions, where are located interference fringes with a nearly same behaviour (spatial frequency, curvature, etc). Connecting these regions and numbering of interference fringes along the connection lines we can obtain correctly numbered fringes. In some practical cases it is also useful to add a substantial degree of tilt with the spatial carrier frequency f in the interferogram. In such a way the problem with ambiguity of fringe numbering can be solved. If the spatial carrier frequency is larger than the maximal value of the gradient of phase values $\Delta\varphi$, i.e. $f > \max|grad(\Delta\varphi)|$, then the fringes can be successively numbered in the direction of the spatial carrier frequency.

4. Conclusion

The presented paper deals with several proper methods for the analysis of interference fields. It is a very frequent case in practice, when the interferometric measurement has to be evaluated on the basis of one recorded interferogram, e.g. in optical testing. The recorded interference field can be then evaluated due to the shape of interference fringes that are characterized by the extrema of the detected intensity of the interference pattern. An automatic identification and numbering of interference fringes are very important parts of the mentioned evaluation process. In this article were described several suitable approaches for correct and fully automatic identification and numbering of interference fringes using mathematical tools of Matlab.

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References:

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