UDC 004.932.2

L. G. Akhmetshina*

Oles Honchar Dnipropetrovsk National University, Dnipro, Ukraine
**e-mail: akhmlu@mail.ru*

METHODS OF VIRTUAL INTERFEROMETRY USED FOR LOW-CONTRAST IMAGE PROCESSING

It is proposed to use virtual analogues of interferometric methods of physical measurements for analyzing the low-contrast images. Different versions of modularly transforming the original image brightness into such a form that makes possible to apply principles and mathematic formalism of real physical methods of measurement are considered. The modulation parameter value impact on sensitivity and resolution of the obtained result is investigated. Such approach allows to synthesize and analyze a number of additional characteristics, which are inaccessible for the hardware representation, and to apply locally-adaptive versions of methods based on the use of window transformations, so opening the possibility of improving the self-descriptiveness of the topological component. Results of experimental verification with the help of numerical models and real images of various types are presented.

Keywords: low-contrast image, interferometric method, virtual characteristics, amplitude-phase characteristics, modulation parameter, sensitivity, adaptability.

Представлено можливості використання віртуальних аналогів інтерференційних методів фізичних вимірювань у задачах аналізу слабоконтрастних зображень.Розглянуто різні варіанти модуляційного перетворення вихідних значень яскравості зображень до такого вигляду, який забезпечує можливість застосування відповідних ідей і математичного формалізму реальних фізичних методів. Досліджено вплив значення параметра модуляції на чутливість і роздільну здатність результату. Такий підхід дозволяє синтезувати й аналізувати низку додаткових характеристик, які недоступні за апаратної реалізації, та використовувати локально-адаптивні варіанти методів на основі використання віконних перетворень, що відкриває можливість підвищення внеску топологічної складової. Представлено результати експериментальної перевірки на числових моделях і реальних зображеннях різного типу.

Ключові слова: слабоконтрастні зображення, інтерференційний метод, віртуальні характеристики, амплітудно-фазові характеристики, параметр модуляції, чутливість, адаптивність.

Представлены возможности использования виртуальных аналогов интерференционных методов физических измерений в задачах анализа слабоконтрастных изображений. Рассмотрены различные варианты модуляционного преобразования исходных значений яркости изображений к такому виду, который обеспечивает возможность применения соответствующих идей и математического формализма реальных физических методов. Исследовано влияние значения параметра модуляции на чувствительность и разрешающую способность результата. Такой подход позволяет синтезировать и анализировать ряд дополнительных характеристик, которые недоступны при аппаратной реализации, и использовать локально-адаптивные варианты методов на основе использования оконных преобразований, что открывает возможность повышения вклада топологической составляющей. Представлены результаты экспериментальной проверки на числовых моделях и реальных изображениях различного типа.

Ключевые слова: слабоконтрастное изображение, интерференционный метод, виртуальные характеристики, амплитудно-фазовые характеристики, параметр модуляции, чувствительность, адаптивность.

1. Introduction

Within the framework of the mission of computer vision, it is possible to use virtual analogues of real physical methods applied for processing radio-physical and optical signals and fields and their mathematical models for the purpose of improving the sensitivity and resolution of visual analysis of different images. In this view, low-contrast images present particular interest due to difficulty of their processing as they are characterized by changes of original brightness which can not be detected by eye. However, very often, objects of interest needed to be detected present a small sector which could be taken as a noise or defect of a picture, and their parameters could inessentially differ from the total background.

It is known that the best sensitivity in optical measurements is provided by holographic [1], ellipsometric [2], and interferometric [3] methods which are based on the wave and polarization properties of the coherent electromagnetic radiation.

In order to create a virtual analogue of the interferometric method and to improve visual analysis sensitivity of the low-contrast images, it is necessary to transform original data into such a form which would make possible to apply the interferometry principles and mathematic formalism. At the same time, in contrast to physical measurements, a virtual space gives an opportunity to synthesize and analyze some additional characteristics, which are inaccessible for the hardware representation, and to apply locally-adaptive options and, consequently, to improve the self-descriptiveness of the topological component in the original data.

2. The presentation of methods

A virtual digital analogue of interferometric method can be realized through the following modular transformation:

$$\mathbf{R}(x,y) = I(x,y)e^{j\pi\frac{I(x,y)}{\lambda}} = \mathrm{Re}\{\mathbf{R}(x,y)\} + j\,\mathrm{Im}\{\mathbf{R}(x,y\} = |\mathbf{R}(x,y)|e^{j\Phi(x,y)} \qquad (1)$$

where $I(x,y)$ is an original image, and $\lambda \leq 1$ − is modulation parameter, which is considered as a virtual analogue of the «wave length of coherent optical radiation» in the analog circuit of the holographic interferometry [4]. Such approach provides the transition from the domain of real brightness rates to the plane of complex values and makes possible to apply mathematical tools from the complex variable theory [5]. $\mathrm{Re}\{\mathbf{R}(x,y)\}$, $\mathrm{Im}\{\mathbf{R}(x,y\}$, and $\Phi(x,y) = I(x,y)/\lambda$ are considered as new informative parameters.

The distinctive feature of the obtained function $\mathbf{R}(x,y)$ is the fact that its amplitude-space characteristic (ASC) (module $|\mathbf{R}(x,y)|$) corresponds to the original image $I(x,y)$, whereas its phase-space characteristic (argument $\Phi(x,y)$ − is a vector rotation degree in the complex plane) depends upon the ratio $I(x,y)/\lambda$. The parameter λ variation effects the variability of the phase characteristic $\Phi(x,y)$ and makes possible to synthesize new virtual images, which are characterized by the different rate of sensitivity to variable values of the pixel brightness.

Before considering the physical analogues, let us consider informative possibilities of the direct application of modulation transitions (1). Fig. 1 a and 1 b show curves $\mathrm{Re}\{R\}$, $\mathrm{Im}\{R\}$, and $\arg\{R\} = \Phi$ that vary depending on the varying normative value of the intensity I for two values of the modulation parameter $\lambda = 0.10$ and $\lambda = 0.25\ \lambda$. The parameter λ is considered as a virtual analogue of the «wave length of coherent optical radiation» in the analog circuit of the holographic interferometry with the reference wave assumption.

Like in the case with the real interferometric wave measurements, the modulation transformation leads to the result ambiguity; besides it, sensitivity of $\mathrm{Re}\{R\}$ and $\mathrm{Im}\{R\}$ increases in the domain with the higher rate of brightness, whereas sensitivity of the phase characteristic is constant within the total range of the brightness. The parameter λ variability effects the variability of the characteristics and makes it possible to adapt the transformation function to the function of distribution of brightness characteristics in the original images and to obtain virtual images characterized by different sensitivity to the variable values of the pixel brightness in the raster presentation of digital images. This fact requires consideration of the transformation characteristics for various values within the range of $(0 \div 1)$.

The minimal change of the brightness intensiveness in the images is 0.4% when a monitor with 256 levels of grey is used. Fig. 1 shows curves of the modulation transformation phase difference that varies to the brightness jump depending on the parameter λ value.

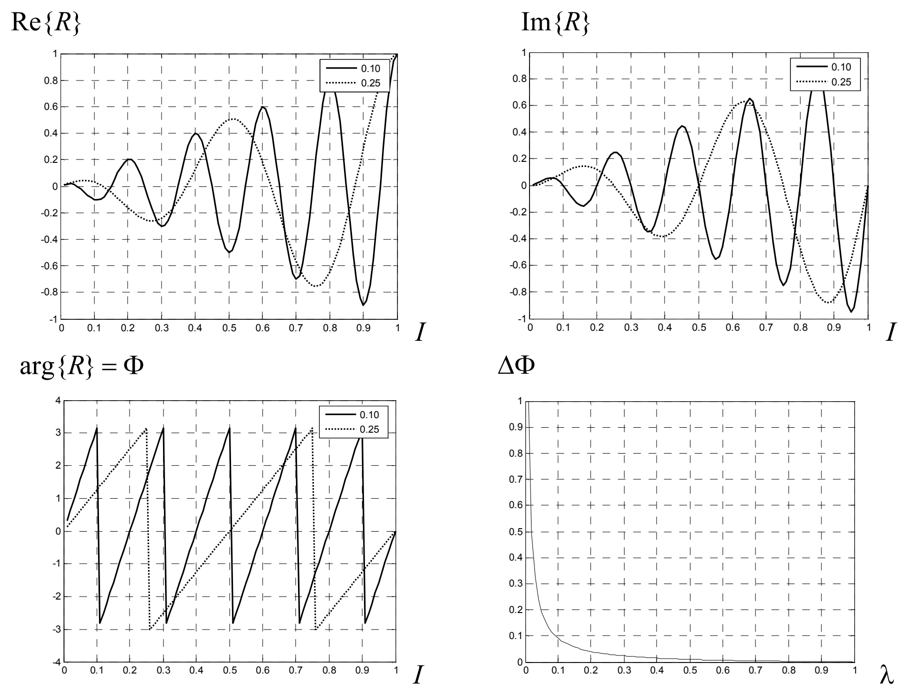


Fig. 1: Curves of varying modulation transformation characteristics

When $\lambda \le 0.13$, the phase shift is more than 5% and, therefore, it makes possible to identify the imperceptible intensifications visually, by the phase characteristic. It follows from (1) that the unambiguity of the results is ensured when $\lambda = 1$, though sensitivity to the variations of the brightness values is reduced in this case.

Usage of the phase (i.e. pure angular) modulation transformation

$$\mathbf{A}(x, y) = \exp\left[j\pi I(x, y)/\lambda\right] = \mathrm{Re}\left\{\mathbf{A}(x, y)\right\} + j\,\mathrm{Im}\left\{\mathbf{A}(x, y)\right\} \qquad (2),$$

and introduction of the virtual coherent reference field $\mathbf{B}(x,y)=1$ with the value $|\mathbf{B}(x,y)|=|\mathbf{A}(x,y)|=1$ and the permanent direction along the axis «x» help to create a virtual analogue of the phase-contrast microscopic method [6], in which differences in the phase characteristics are transformed into differences of amplitudes and the result of the vector summation of measured (passing through the object) and reference luminous fluxes is registered. This approach gives an opportunity to register only the phase differences between the light passing through the various areas.

Here, unlike to the expression (1), the amplitude modulation is substituted by the complex angular (pure phase) modulation and can be used for improving the quality of "phase-contrast" images.

The virtual analogue peculiarity is that not only the module of the vector sum but also differences of these two vector fields can be used as an informative parameter

$$|\mathbf{R}(x,y)|_{\pm}=|\mathbf{A}(x,y)\pm\mathbf{B}(x,y)|. \tag{3}$$

Choosing a concrete value for the «x» is dictated both by peculiarities of the image to be analyzed and the objectives of the analysis. As researches have shown, for cases when area of interest is specified, the choice of the following value is reasonable

$$\lambda \approx (1.01 \div 1.1)\left[I_{\max}(x,y)-I_{\min}(x,y)\right] \tag{4}$$

where $I_{\max}$ and $I_{\min}$ is maximal and minimal values of the image brightness (amplitude) in the area of interest. Depending on the spatial distribution of the brightness intensiveness in the original images, the detection of imperceptible changes in the brightness rate can lead to different values of the transformation parameter λ.

Transformations (1) and (2) refer to the integral class as the parameter λ («wave length of coherent optical radiation») is the same along the total length of its aperture. The implementation of adaptive local option, which is based on the usage of "sliding windows", allows to take into account peculiarities of certain sectors of the images. In this case λ is a variable quantity and its value depends upon the current pixel coordinate.

In cases where the adaptive approach is implemented for each pixel of the image $I(x,y)$ should be analyzed within the size of $(L\times L)$ of the used sliding frame It allows to take into account the effect of the nearest neighbours and topological peculiarities of the original data ($L=3$ is enough for most of the applications); a value for the modulation parameter is calculated in the following way

$$\lambda(x,y)=I_{L,\max}-I_{L,\min}+k \tag{5}$$

where k is a stabilizing coefficient determined through the empirical way. Its value should be chosen depending upon original dynamic range of the image brightness changes.

3. Experimental results

Fig. 2 presents result of usage of the method, which is based on synthesis of characteristics with applied transformation (1), for the numerical model. This image includes invisible smooth changes of the field which is formed by numerous of sources among which only some of them are visible from the origin point.

As the above approach is integral, it is reasonable to consider its informative possibilities on the example of its comparison with the widely spread integral method of the image processing – the histogram equalization [7]. Good results on detecting invisible "sources" were obtained by using characteristic $\mathrm{Re}\{R\}$ of the modulation transformation (1) with modulation parameter $\lambda = 0.17$ (fig. 2 c), though the best description of the field structure was obtained by the phase characteristic $\lambda = 0.03$ (fig. 2 d).

Application of multiple histogram equalization slightly improves visual quality of the image due to the brightness values redistributed over entire range of their gradation and helps identifying dark and bright areas; at the same time, it reduces sensitivity of the analysis because initially visible sources of the field disappear (fig. 2 b).

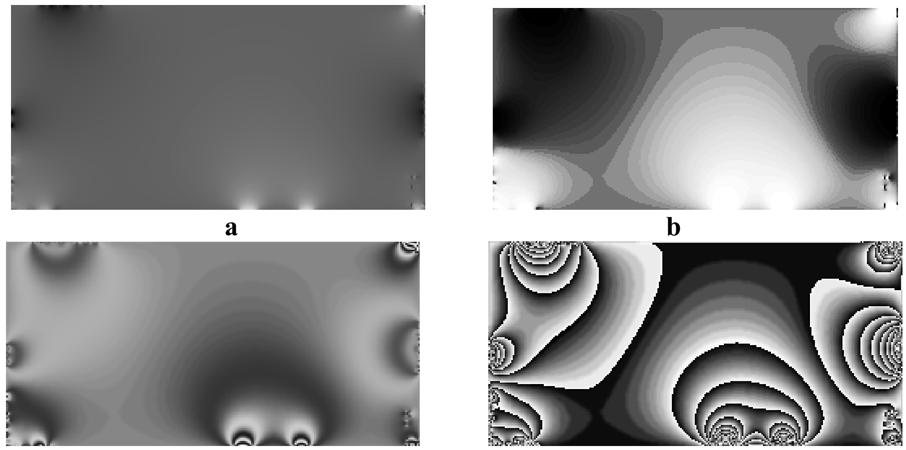


Fig. 2. Digital simulation: a — an original image; b – result of histogram equalization method;

c– $\mathrm{Re}\{\mathrm{R}(x, y)\}$ of (1) $\lambda = 0.03$; c – phase characteristic $\Phi(x, y)$ of (1) $\lambda = 0.03$

Analysis of the image histograms, which are obtained on the basis of the synthesized interference characteristics, leads to the following conclusions:

–dynamic range of the synthesized image brightness is twice and thrice, respectively, wider than dynamic range of the original image;

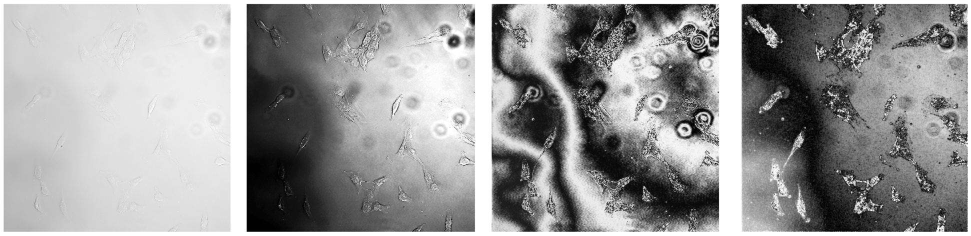
– maximum of the image histogram $\Phi(x, y)$ ensures optimal distribution of the brightness (see middle part of the brightness range in the fig. 2 d) and improves perceptive sensitivity of the visual analysis;

–in practice, it is possible to adjust parameters of the method in such a way, that characteristics will be sensitive to the required range of the space local brightness.

Fig 3 presents microbiological image processed by interferometric method and its adaptive variant. Differing interferometry picture of the dissimilar biological structures helps to obtain more exact description of both interface between the structures and the common background structure.

The adaptive variant of the method gives more sharp picture of the object structure. The experiments have shown that if a value $k \leq 0.1$ is chosen for the expression (5), the analysis can be difficult due to presence of numerous phase jumps in the synthesized interferometric image. It has been empirically established that the value within the range $k = 0.2 \div 0.4$ is optimal for the frame with the size 3x3 for the most of the image types.

In this analysis, visualization of the $\mathrm{Re}\{\mathrm{R}(x, y)\}$ reveals peculiarities of light areas in the low-contrast images, and visualization of the phase characteristic $\Phi(x, y)$ helps to see clearly a structure of the dark areas. Usage of the two characteristics allows to identify all visually indiscernible areas.

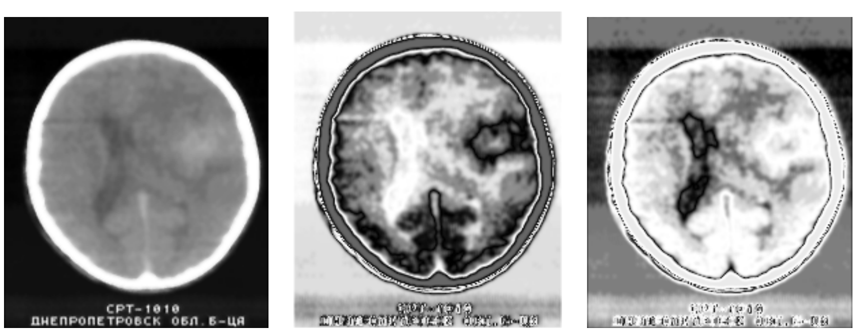


а б в г

Fig. 3. Analysis of the optical microbiological image: a – an original image; b – result of the histogram equalization method; $\mathrm{Re}\{\mathbf{R}(x, y)\}$ of the interferometric method ($\lambda = 0.03$) в – result of the adaptive interferometric method ($k = 0.2$)

Fig. 4 presents results of processing of the brain tomogram based on visualization of the characteristics (3) at $\lambda = 0.03$. The procession was resulted in the brightness redistribution, and the extremes of the histogram (Fig. 2.14 c, d) were displaced into location, which was most suitable for the visual analysis, i.e. substantially into the middle of the range. This fact allows to confidently identify in the dependence $|\mathbf{R}(x, y)|_+$ a sector with possible pathology, which appears in the form of abnormal dark area in the middle part of the synthesized image.

Comparative efficacy of their usage essentially depends on specific nature of the object to be analyzed. When image (or its local sector) is homogeneous enough, it is reasonable to use vector difference module, and when the picture features significant brightness jumps, it is reasonable to use characteristic $|\mathbf{R}(x, y)|_+$.

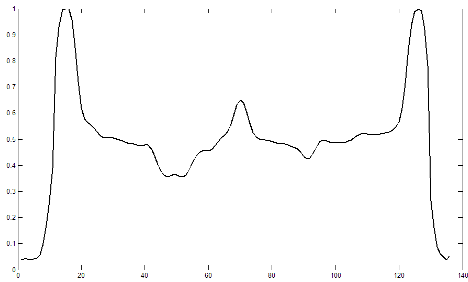


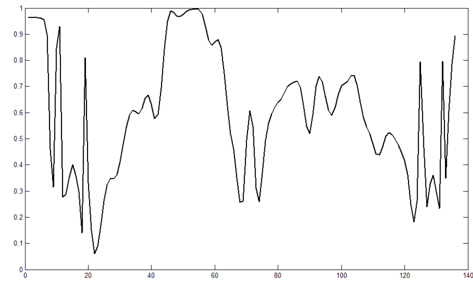
a b c

Fig. 4. MR image of a brain: a – original image; b – $|\mathbf{R}(x, y)|_+$, c – $|\mathbf{R}(x, y)|_-$

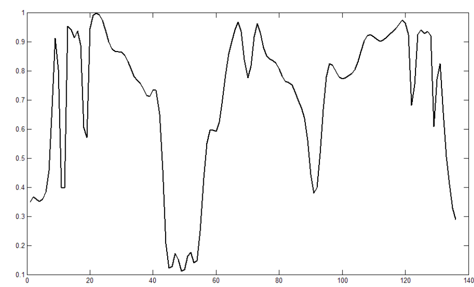
Analysis of spatial and amplitude sections of the lines in the informative area of the synthesized image (fig. 5) shows that the dynamic range of the brightness variation in the region of interest has increased by about 4,5 times (in this example - from 20% to 85%) resulting in higher reliability of visual analysis.

A lot of experiments were carried out with low-contrast medical images. All of them confirmed high sensitivity of the method for the segmentation of low-contrast medical images.





a **b**



c

Fig. 5. Amplitude-spatial slice images of the 100th line in fig. 4 a, b, c, respectively

4. Conclusions

Application of virtual analogues of the optical interferometry methods presents a simple and useful tool, which can essentially improve visual analysis of the low-contrast images. Thanks to the essential nonlinearity of the synthesized characteristics, which can be regulated by a modulation parameter, it becomes possible to adapt transformation function into function of the brightness distribution in the original images and to control a self-descriptiveness rate of the synthesized characteristics of the complex modulation transformation.

References

1. **Rastogi, Pramod K.** Holographic Interferometry: Principles and Methods [Text] / Pramod K. Rastogi. – Springer. 2013. - 329 p.

2. **Tompkins, H.** Handbook of Ellipsometry [Text] / Harland Tompkins, Eugene A Irene. - William Andrew.- 2005. - 886 p.

3. **Germain Chartier** Introduction to Optics [Text] /Germain Chartier. - Springer - 2005 . - 595 p.

4. **Hariharan, P.** Basics of Interferometry [Text] / P. Hariharan. - Academic Press. 2010. - 248 p.

5. **Ahmetshina, L.G.** Information possible modulation conversion with segmentation of multispectral images [Text] / L.G. Ahmetshina // System technology. – 2004. – № 6.–P. 122-127.

6. **Heinrich Durege.** Elements of the Theory of Functions of a Complex Variable: With Especial Reference to the Methods of Riemann [Text] / Heinrich Durege. -BiblioBazaar,- 2015. - 308 p.

7. Chang, William S. C. Principles of Optics for Engineers [Text] / William S. C. Chang. - Cambridge university press. 2015. -225 p.

Received 15.05.2016.