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Histogram equalization and specification in interferometry

M. ROSU*, B. IONITA, D. APOSTOL, F. GAROI, P. C. LOGOFATU
Lasers Dept., National Institute for Laser, Plasma and Radiation Physics, PO Box MG-36, 077125, Magurele, Romania

Equalization of histogram is used to process photographic digitized images composed mostly of pixels that are either very dark or very bright components. Equalization provides equal distribution of the number of pixels over the intensity range, which results in increased contrast and highlighted details. We apply here the histogram equalization to maximize the discernible number of fringes in a speckle pattern interferometry image, maximize the contrast of fringes and correct uneven exposure. When fitting the interferogram to a sinusoidal fringe pattern for phase determination, the closeness to the sinusoidal shape is important. Histogram processing allows ideal or near-ideal sinusoidal fringes to be obtained from non-sinusoidal patterns.

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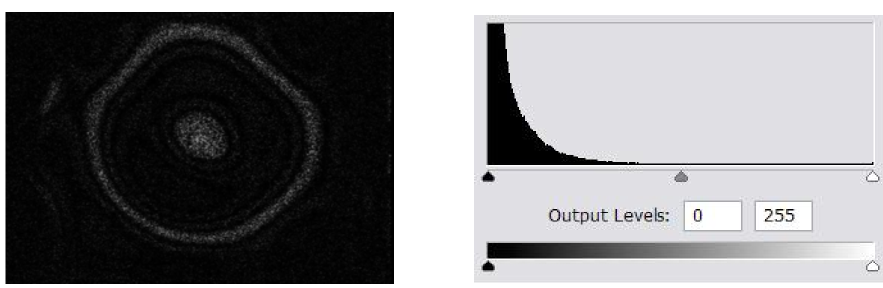
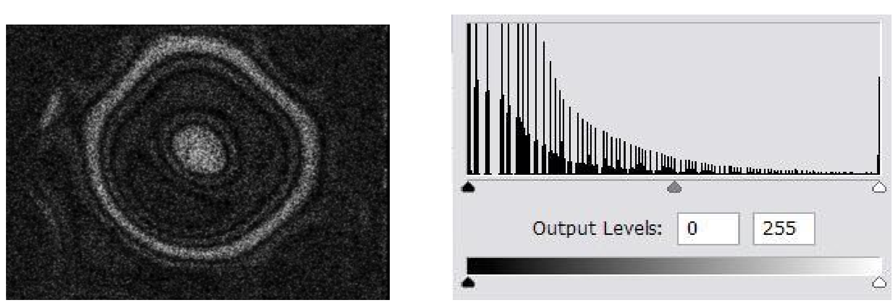
1. Introduction

The computer and the digital camera revolutionised interferogram processing; first by prompt digital recording and viewing, and second by allowing the use of the large already existing arsenal of digital methods to improve the quality of photography. In this paper we endeavour to illustrate the simple digital application of histogram equalization in interferometry and the spectacular improvement that it brings to information extraction from the image.

The most common format that is in use in today's digital photography is 24-bit RGB, with the colour of each pixel being obtained by the superposition of the three 8-bit channels, red, green and blue, each having its own particular luminance intensity. The 8-bit colour channels have, obviously, 2^8=256 levels of intensity. The histogram of a digital image plots the numbers of pixels in the image versus the brightness levels. Basically, it shows how the luminance values in a digital or digitized photograph are distributed [1].



(a)



(b)

Fig. 1. Example of originally underexposed interferogram (a) and the same interferogram with equalized histogram (b). The images of the interferograms are on the top and the associated histograms are on the bottom.

The histogram maps the distribution of the luminance values for each channel separately or added together. In this article, we converted the image to grey-scale and we treated specifically this case. The plot of the histogram is influenced by several factors: colour space, bit depth, image compression level and format [1].

2. Histogram equalization

Our goal is to enhance an image for fringe analysis purposes by equalizing its histogram if the original has a too few grey levels of significant weight, or is lacking contrast [2]. This approach can also indicate and correct more subtle problems related with under and over exposure.

For example, the digitized speckle pattern interferogram from Fig. 1 (a) has the majority of the grey levels bunched between about 0-50. It is a clear example of underexposure. So, given this data, the question is how can we modify the image so that we can make the fringes more visible and even be able to assess their shape. The goal of histogram equalization in this case will be to expand the intensity levels so that to occupy the entire 0-255 spectrum of intensity levels and to distribute in a more even way the intensities on the histogram. This allows for areas of lower local contrast to gain a higher contrast without affecting the global contrast. Histogram equalization accomplishes this by spreading out the most frequent intensity values [2].

3. Implementation

Consider a discrete greyscale image, and let n_i be the number of occurrences of grey level i. The probability of an occurrence of a pixel of level i in the image is

$$p(x_i) = \frac{n_i}{n},\ i \in 0,\ldots,L-1, \tag{1}$$

where L is the total number of grey levels of the digital image, n the total number of pixels in the image, and p the image histogram normalized to 1.

Let us also define c as the cumulative distribution function corresponding to p, defined by

$$c(i) = \sum_{j=0}^{i} p(x_j), \tag{2}$$

also known as the image accumulated normalized histogram. We want to create a transformation of the form $y = T(x)$ that will produce a level y for each level x in the original image, such that the cumulative probability function of y will be linearized across the value range [3]. The transformation is defined by:

$$y_i = T(x_i) = c(i). \tag{3}$$

Notice that T maps the levels into the domain (0.1). In order to map the values back into their original domain, the following simple transformation needs to be applied to the result:

$$y_i' = y_i(\max - \min) + \min, \tag{4}$$

where max and min are the maximum and the minimum values of the y_i' domain respectively. Manually adjusting the histogram implies three steps:

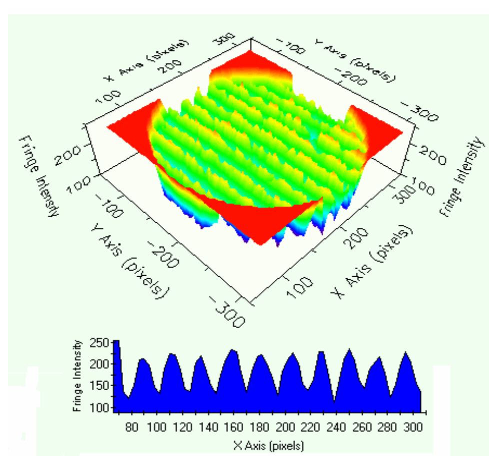
- adjusting the low-tones (shadows),
- adjusting the high-tones (highlights),
- adjusting the mid-tones. [3]

4. Histogram specification

This method implies the manipulation of the initial histogram with the intention of obtaining a specific profile. For instance if we have a digitized interferogram with a non-sinusoidal profile we can, in certain limits, obtain a sinusoidal profile for that interferogram just by trying to bring the original histogram into the shape of a histogram associated with a theoretically generated interferogram with a perfect sinusoidal profile.

The tool that we used in this specification is called "Intensity Curve" [3] and it is an interactive diagram that can continuously and smoothly associate new output values for the input levels that we want to change in order to specify that histogram. This technique combined with the real time monitoring of the histogram allows the actual specification trough a process of trial and error.

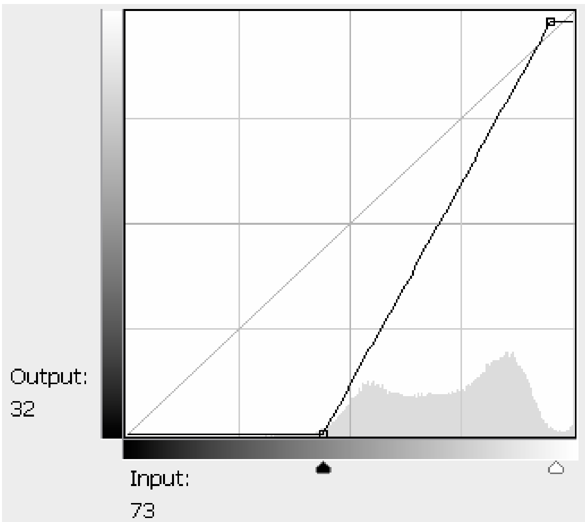
(a)



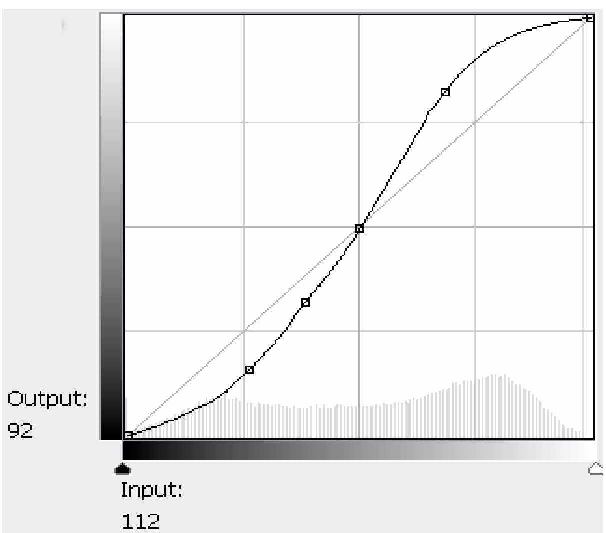
(b)

Fig. 2. Original interferogram with 3D plot and profile at coordinate Y 156.

We exemplify the entire process in the Figs. 2-4. The 3D plot and profile are obtained with an interferometric analysis computer programme called IntelliWave™. One can observe the results of histogram specification comparing the initial profile from Fig. 2 with the resulting one from Fig. 4.



(a)

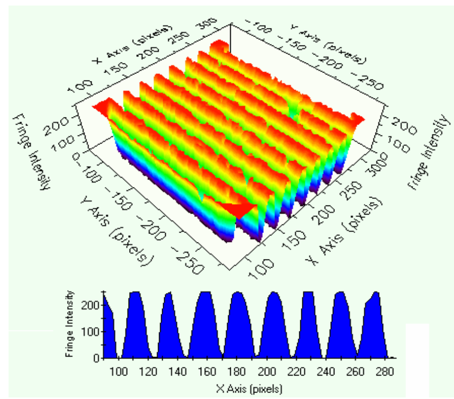


(b)

Fig. 3. Intensity curve, tool for histogram specification.

In Fig. 3, we presented the two steps of the specification process. In the first one, which is practically histogram equalization, we expand the overexposed grey levels on the entire dynamic range of 256 levels.

(a)



(b)

Fig. 4. Interferogram after specification with 3D plot and profile at coordinate Y 156.

The actual histogram specification is accomplished in the second step where we manipulate the levels in such a way that the final profile taken at the same coordinates becomes almost a sinusoidal one. In addition, we can see a dramatic improve in contrast between original and specified interferogram.

5. Conclusions

The results we obtained using histogram equalization and specification greatly improve the contrast of the original interferograms, thus increasing the accuracy of fringe counting and fitting. Greater accuracy here implies better reconstruction of the phase distribution.

References

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*Corresponding author: dan.apostol@inflpr.ro