Comparative study of the spectral selection based on image compression methods

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Abstract

Objectives: To investigate the image compression methods based on spectral selection and to carry out a comparative study.

Methods: The technique consists of comparing pixel by pixel the spectra of the images being compressed. To identify the winner among the spectral pixels, we investigated three forms of information, namely the intensity of the pixel in question, its complex gradient and its phase gradient. To separate the images in the output plane, after applying a second Fourier transform, the retained pixel must integrate the carrier specific to the corresponding spectrum. In addition to these forms, we considered three options of selection, namely the selection of the pixel with the most important amount of information, the selection with respect to a fixed probability function and finally the selection based on a matched probability function. This leads to nine methods of compression. These methods were also compared to the method which consists in merely adding the spectra and inserting a carrier specific to each one.

Results: the quality of image reconstitution are assessed by two metrics namely diffraction efficiency and root mean square error. We observed that for any form of information on the basis of which the selection is performed, the matched probability function yields a better result. The methods based on the gradients privilege contour information.

Conclusions and perspectives: Whatever the retained method is, the number of images to be compressed is very limited. It depends on the bandwidths of the images. In perspective, we plan to integrate the bandwidth in the spectral selection. The binarization of the obtained spectrum will be also the subject of a future work.

1. Introduction

In the present paper we investigate a recently proposed method of optical image compression. The compression is carried out in the spectral domain and results in a combined spectrum referred to as the segmented spectrum. Enough amounts of relevant information should be selected from each spectrum to reconstruct the respective images. All amounts are the merged together to form a unique spectrum. To separate the images in the output plane, after applying a second Fourier transform, the segmented spectrum should include a distinct carrier for each spectrum [3]. In order to identify the method offering the best reconstruction of the optically compressed images, we intend to investigate several spectral segmentation based methods by undertaking a comparative study. In perspective, we plan to extend the study to 3D as well as color images.

In our simulation, we used four reference images. For illustration, we have chosen an image of the first Arabic alphabet letter (alif) and three images containing the Latin alphabet letters "a, b, c" respectively, as shown in Figure 1.

The selection of the zones of each spectrum, the most representing of the respective image, requires the definition of an appropriate selection criterion. Three basic criteria are used to select the winning pixel: selection in function of 1) the intensity of the pixel, 2) its complex gradient or 3) its phase gradient. Moreover, we introduce three selection options: the winner according to the chosen criterion (intensity, complex gradient, phase gradient) is retained 1) automatically 2) with respect to a predefined probability function and finally 3) with respect to a matched probability function.

To separatee the images in the output plane, after applying a second Fourier transform, each retained pixel must include a carrier specific to the corresponding spectrum. This leads to nine methods of compression. These methods were also compared to a tenth method which consists in merely adding the spectra and inserting a carrier specific to each one. The tenth method suffers from a major disadvantage. It does not allow of the implementation of a filter specific to one reference because all the pixels of the Fourier plane belong to all references.

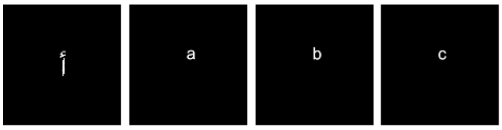

Figure 1 : The reference images

2. Criteria and options of compression

2.1 Intensity criterion

For a given position (i,j) of the Fourier plane, the technique consists in comparing the pixels of all spectra located at this position. It is worth noting that the spectra are normalized to a common fixed energy E0, say the unit (E0=1). The winning pixel among the four pixels of the respective spectra possesses the biggest intensity [4]. In other words, the importance of information is expressed by the intensity of the pixel. The pixel at the position (i,j) of the spectrum k is retained if:

$$E_{i,j}^{k} > \begin{cases} E_{i,j}^{0} \\ E_{i,j}^{1} \\ . \\ . \\ . \\ E_{i,j}^{L-1} \end{cases} \qquad (1)\ l = 0,\ldots,L-1$$

Where L is the number of classes (images) and $E_{i,j}^{k}$ is the intensity of the pixel (i,j) of the image k.

We add to each class in the spectral field a specific carrier in order to separate the various classes in the exit plan after a second Fourier transform as shown in Figure 2.

To separate the various classes in the exit plan after a second Fourier transform, a specific phase term (carrier) of each class is added in the spectral plane as shown in flowchart of Figure 2.

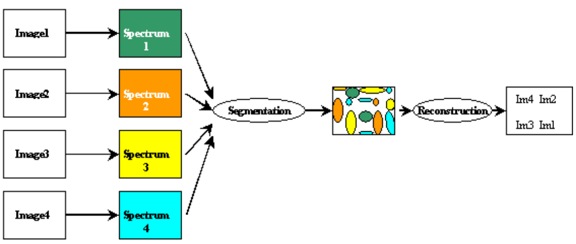

Figure 2 : Segmentation and reconstruction method

The intensity criterion suffers from two drawbacks, 1) all non-winning pixels (loosers) in generally large zones are ignored, even if the intensities of some loosers are close to that of the winner, 2) it neglects the importance of the phase during the selection. To overcome these drawbacks, we investigated other methods.

2.2 Complex gradient criterion

The previous criterion focuses on the intensity of the pixel and disregards the behaviour of its phase [5]. To take into account the phase, we propose to consider the complex gradient instead of the intensity. The complex gradient is calculated according to equation (2).

$$S(u,v) = A(u,v).e^{j\varphi(u,v)}$$

$$\nabla S(u,v) = \begin{bmatrix} \dfrac{\partial S(u,v)}{\partial u} \\ \dfrac{\partial S(u,v)}{\partial v} \end{bmatrix} \Rightarrow$$

$$|\nabla S(u,v)|^2 = \left|\frac{\partial S(u,v)}{\partial u}\right|^2 + \left|\frac{\partial S(u,v)}{\partial v}\right|^2 \qquad (2)$$

$S(u,v)$ is the image spectrum and $\nabla S(u,v)$ is the complex gradient of spectrum.

The complex gradient can be expressed in terms of amplitude and phase as follows:

$$|\nabla S(u,v)|^2 = |\nabla A(u,v)|^2 + |A(u,v)|^2 |\nabla \varphi(u,v)|^2 \qquad (3)$$

Both amplitude and phase variations are taken into account during the selection process. However, when the amplitude varies more rapidly than the phase, amplitude information will dominate. This situation is very frequent and represents a drawback for this method which then doesn't present a significant improvement with respect to the previous one.

2.3 Phase gradient criterion

Instead of considering all the terms of equation (3), we limit ourselves to that of the phase variation, namely $\nabla\varphi(u,v)$:

$$\nabla\varphi(u,v) = \begin{bmatrix} \dfrac{\partial\varphi(u,v)}{\partial u} \\ \dfrac{\partial\varphi(u,v)}{\partial v} \end{bmatrix}$$

$$\Rightarrow |\nabla\varphi(u,v)|^2 = \left|\frac{\partial\varphi(u,v)}{\partial u}\right|^2 + \left|\frac{\partial\varphi(u,v)}{\partial v}\right|^2 \qquad (4)$$

Since the criterion focuses on the phase variation and disregard amplitude information in the selection process, the drawback of the previous criterion is overcome.

The gradient approaches (complex or phase) are insufficient because, like the intensity criterion, one spectrum can be the winner for a large continuous zone. To ensure a better representativity for all the spectra, a spectrum should have a chance be represented in the zone dominated by another spectrum according to the criteria defined above. For this purpose, we intend to introduce a probability function which allows some initially loosing pixels to be selected. We recall that the objective is to obtain an equitable representation of the spectra.

3. The probability functions

The spirit of the introduction of a probability function is to not neglect any pixel in the selection. The resulting segmented spectrum should contain information on the respective spectra equitably.

To introduce the probability function, we proceeded in two different ways. The first consists in fixing the rates from the beginning and independently of the pixel position and the values of the spectra at this pixel. We have chosen four probabilities 60%, 25%, 10% and 5%. The winning pixel according to the used selection criterion (intensity, complex gradient or phase gradient) will be retained with a probability of 60% rather than automatically.

The pixel which comes in the second place according to the same criterion, has less chance to be retained (25%). It is hard likely (10%) that the pixel which comes in third place will be retained. Lastly, though very small in value, the chance to retain the pixel which comes in the last place exists (5%). A drawback results from this kind of selection. The probability to retain a pixel depends on its order in the pool of importance according to the given criterion. The value attributed to the pixel with respect to the criterion is not taken into account. For example, if with respect to the criterion (intensity, ...), the difference between the first and the second pixel is very small, the chance of the second to be retained is unchanged, namely 25%. Thus, we suggest an alternative for the probabilistic selection. The idea is to match the probabilities to the importance of the pixel with respect to the chosen criterion.

The matched probabilistic selection is also based on the classification of the pixels by their importance. However, unlike the fixed probability based selection, it does not neglect the importance of one spectral pixel compared to its homologues at the same location in the other spectra. Indeed, when the difference of importance between the first and the second pixel with respect to a chosen criterion increases, the chance of the second to be retained decreases proportionally. If the difference becomes relatively very small, the chances to retain the first or the second become almost identical. This technique is expected to offer a significant improvement of the reconstruction quality.

4. Reference method

The principle of this method is very simple. It consists in adding the spectra and introducing a carrier specific to each one. This method, however, does not include segmentation.

5. Results

In order to compare the nine methods (three criteria and three options of selection), we opted for the diffraction efficiency and the root mean square error (rms). The diffraction efficiency η is defined as the ratio of the energy of reconstructed image to the total energy of the reconstruction plane.

The results are summarized in Table I. We note that the complex gradient method offers no improvement for two images (1 and 2) neither in terms of diffraction efficiency (η) nor in terms of quality (rms). For image 3 when no matched probability selection is applied, there is a slight improvement with respect to the intensity criterion (column 3 compared to column 2 and column 6 compared to column 5). For image 4, the complex gradient gives a slightly higher diffraction efficiency compared to the intensity criterion only if we apply the matched probability selection. Our interpretation is that the amplitude variation might be dominant on phase information. Compared to the method based on the complex gradient, the phase gradient criterion offers an improvement for three images (1, 2, and 3) in terms of reconstruction quality (rms) but not in terms of diffraction efficiency (η). This is valid for all the three selection options (intensity, fixed probability and matched probability) except for the image 3 where a slight improvement in terms of diffraction efficiency is observed (columns 6, 9 compared to columns 5, 8 respectively). This demonstrates the importance of the phase variation in the selection criterion. However, in terms of energy, this kind of selection is not advantageous. Like the complex gradient criterion, the phase gradient method privileges the contours of the image, yielding an energy loss. The probability function (fixed or matched) shows a significant improvement of the reconstruction compared to the three methods where the winner is automatically retained. This improvement concerns both reconstruction quality (rms) and diffraction efficiency (columns 4, 5, 6 and 7, 8, 9 compared to columns 1, 2, 3 for all images). Also it is worth noting that the matched probability gives the best results in terms of reconstruction quality (columns 7, 8, 9 compared to columns 4, 5, 6). As diffraction efficiency is of concern, the matched probability function favours image 3 only.

Of course, compared to all the methods, the adding the spectra with an additional carrier specific to each one gives the best result, as shown in column (10) of Table 1 and the figure (4.10). This method does not integrate any segmentation. Thus, it is not possible to design a separate filter for each spectrum.

	winner retained automatically			Fixed probability			matched probability			reference method
	Intensity (1)	Complex gradient (2)	Phase gradient (3)	Intensity (4)	Complex gradient (5)	Phase gradient (6)	Intensity (7)	Complex gradient (8)	Phase gradient (9)	(10)
rms										
Im1	0.0486	0.4246	0.5513	0.0354	0.2015	0.3480	0.0195	0.1360	0.4385	8.2491 10^{-30}
Im2	0.1902	0.3152	0.2637	0.0848	0.0953	0.0716	0.0401	0.0727	0.0155	1.3169 10^{-29}
Im3	0.2871	0.1603	0.0547	0.0693	0.0456	0.0270	0.0131	0.0634	0.0296	8.0818 10^{-30}
Im4	0.1399	0.1553	0.1379	0.0648	0.0510	0.0238	0.0199	0.0544	0.0109	8.2931 10^{-30}
η										
Im1	0.5151	0.2492	0.0957	0.3302	0.1294	0.0716	0.2648	0.1491	0.0602	1.0000
Im2	0.2297	0.2143	0.1258	0.1594	0.1636	0.1140	0.1449	0.1281	0.1222	1.0000
Im3	0.1240	0.1427	0.1879	0.1041	0.1256	0.1455	0.1077	0.0848	0.0997	1.0000
Im4	0.2648	0.2417	0.1521	0.1843	0.1566	0.1197	0.1387	0.1781	0.1460	1.0000

Figure 3: Diffraction efficiency and reconstruction quality for the four reconstructed images

6. Conclusions and perspectives

Our comparative study shows that for any form of information on the basis of which the selection is performed, the matched probability function yields a better result.

The methods based on the gradients privilege contour information. Thus they result in a significant loss of energy (low diffraction efficiency).

Whatever the retained method is, the number of images to be compressed is very limited. It depends on the bandwidths of the images. We note also that the choice of the method depends on the data basis and the permitted losses at the reconstruction plane.

In perspective, we plan to integrate the bandwidth in the spectral selection. The binarization of the obtained spectrum will be also the subject of a future work.

We also intend to extend the approach to integrate 3D and color images.

7. References

1- J.A REIF, A. yoshida « Optical techniques for image compression », IEEE 1992, 32-41.

2- AL FALOU, Ayman « JPEG image compression process based on the use of optics as calculation mainspring ». WSEAS Trans. On information science & APPLICATION, Issue 3, Vol. 1, September 2004, pp. 801-806.

3- A. Al Falou, A. Boumezzough, P. Combon « Optimization of the segmented filter for optical compression and multiplexing system ». Proceedings of SPIE, OPTO-Canada, pages (349-351) volume TD01- 10 May 2002 Ottawa, Ontario Canada.

4- Boumezzough, A. Al Falou, C. Collet « OPTICAL IMAGE COMPRESSION BASED ON FILTERING OF THE REDUNDANT INFORMATION IN FOURIER DOMAIN WITH A SEGMENTED AMPLITUDE MASK (SAM) »,CSIMTA-IEEE-See, Complex Systems, Intelligence and Modern Technological applications (CSIMTA 04), pages (566-570), 19-22 September 2004, Cherbourg-FRANCE.

5- Habib, HAMAM « A new measure for optical performance », Optometry and Vision Science, Vol. 80, No. 2, February 2003.

6- Majdi taha oraiqat, Firas Mohammad Awwad, hazem Munawer AL Otum « A coparison of image enchancement using curvelet transform with multiscal gradient and retinex operators WSEAS Trans. On ELCTRONIC, Issue 3, Vol. 1, July 2004, pp. 461-466.

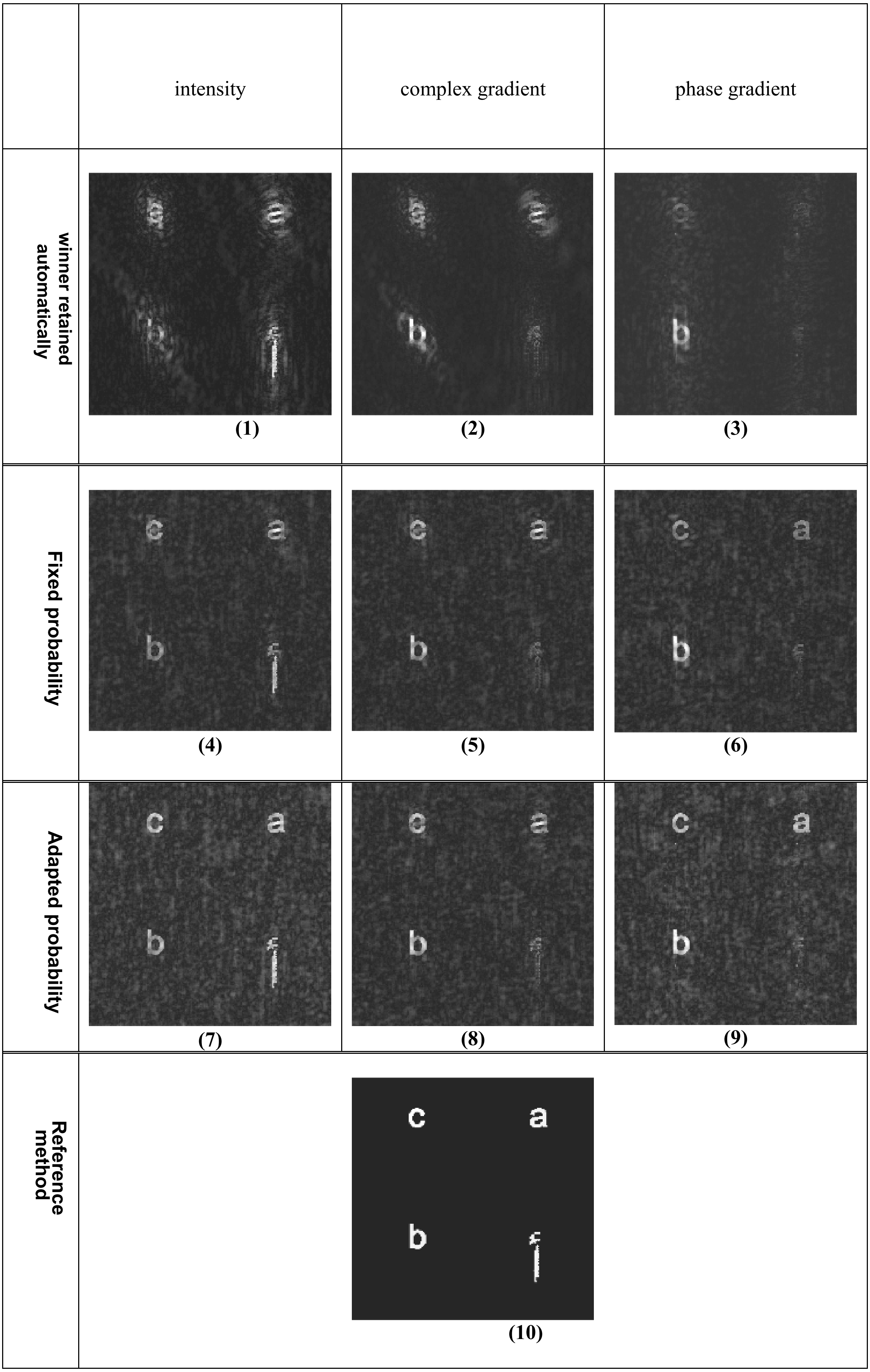

Figure 4 : Image reconstruction by means of the segmented spectrum (except of image 10)