OPTICAL IMAGE COMPRESSION BASED ON FILTERING OF THE REDUNDANT INFORMATION IN FOURIER DOMAIN WITH A SEGMENTED AMPLITUDE MASK (SAM)

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Abstract

Optical computing has recently become a very active research field. The advantage of optics is its capability of providing highly parallel operations in a two-dimensional space. Using these properties we propose, in this paper, a new technique for optical image compression based on a simple multiplication of the image spectrum with the segmented amplitude mask (SAM) in the Fourier domain. The introduction of this SAM has, as a principal objective, to locate the redundant information zones in a given spectrum, by introducing an energetic criterion of selection and segmentation in order to filter them. Numerical simulation results support our proposition and verify the algorithm, and an optical implementation set-up is also suggested.

Key Words

Image compression, image processing, Fourier optic, holography.

1. Introduction

The needs to increase the transmission rates have led to the development of advanced tools due to compression requirement. The compression algorithms have been introduced in order to improve both the transmission speed [1]. In the field of image transmission, electronic implementation of these algorithms for high-resolution and -frame rates images usually requires very expensive electronic parallel processing. In addition, before being compressed, the original images are analogue or digital electrical signals which can then be easily intercepted. The algorithm for images compression which we will present is based on two-dimensional Fourier transform. Whereas the computation of two-dimensional Fourier transform is rather complicated by conventional electronic means, coherent optics makes it possible almost instantaneously [2]. For a long time, this property has been extensively used to make real-time target recognition in a scene (optical correlators)[3]. We will show that the same property can also be used to perform real-time compression of high-resolution and -frame rate images. Moreover, by using this fully optical way, original images are compressed in the camera while being still in an optical form. Only the final compressed image is converted into an electrical form for conventional electronic transmission and/or storage.

2. Principle of fully optical compression

Compared to the electronic techniques, the use of all-optical compression has the advantage of processing the image as a whole [4]. It is in fact a simple multiplication (modulation), in the spectral plane, between the spectrum of the current image to be compressed by one or several well-defined and determinist masks previously manufactured. The Fourier transform $S(X,Y)$ of that coherent input image $s(x,y)$ can then be easily formed by the Fourier lens L_1 in its focal image plane P_2 (so-called Fourier plane) at the coordinates (X,Y). The compression mask, which has a complex transmittance $\rho_{comp}(X,Y)$, is both located in the Fourier plane. Thus, in the first Fourier plane we get the product R between the spectrum of the input image with the compression mask. The Eq. (1) expresses this product.

$$R = S \times \rho_{comp} = S' \qquad (1)$$

where $S' = S \times \rho_{comp}$ is the Fourier transform of the compressed image.

The result of this multiplication, i.e. the spectrum intensity of the compressed image, is imaged onto an image sensor, e.g. a CCD, which performs the opto-electronic conversion needed to interface the optical system with conventional electronics further transmission. However such a quadratic sensor would cancel the phase information of the spectrum required for reconstitution.

Once the image spectrum has been recorded, compressed on a CCD camera, the resulting digital version is sent through a transmission network.

Since the compression method used is known as a loss, the simple fact of carrying out an inverse Fourier transform of the compressed spectrum S' is sufficient to allow image reconstitution.

3. Synthesis of all optical compression

Figure 1 depicts the synoptic diagram of all-optical compression (transmitter).

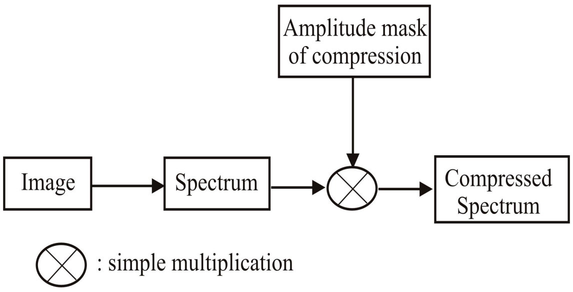


Figure 1 : Synoptic diagram of all optical compression and encryption

Once the image has been read in coherent light, its Fourier transform is carried out, then compressed by multiplying its spectrum with a well-defined amplitude mask. This allows to select zones of interest in their spectral plane, and to eliminate the less significant, and thus redundant zones.

4. Optical compression

The optical set-up and the synoptic diagram detailing the various stages of optical image compression are depicted in figure 2.

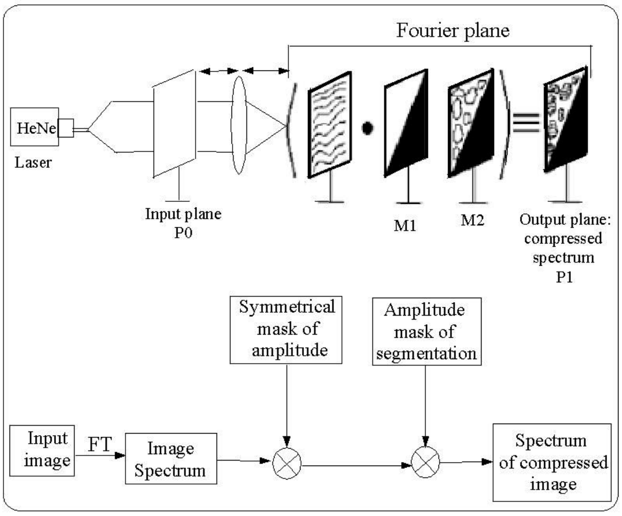


Figure 1 : Optical set up and synoptic diagram detailing the various stages of optical compression. P0 is the input plane, M1 is the symmetrical mask of amplitude, M2 is the amplitude mask of segmentation and P1 is the result of compression of the input image

Once the Fourier transform of an image has been performed with a convergent lens, L_1, placed at a distance, f_1, of the input plane P_0, the spectrum of this image in the focal plane of L_1 is multiplied by a first binary amplitude mask(1,0). This mask, M_1, is symmetric with respect to its diagonal; so, it is transparent (=1) on the upper half above the diagonal and opaque (=0) on the other half. Thus, after the passage of the image spectrum through this mask, only half of the image is kept.

Let us, for example, consider the spectrum of an image in the form f a matrix composed of complex elements (figure 3), each element of the first half of this matrix is combined to an element of the other half [5].

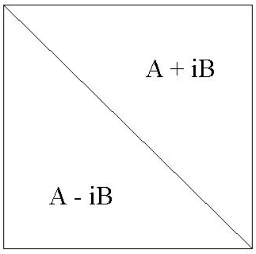


Figure 2 : Complex matrix representing the spectrum of an image

This property is applied to the image shown in figure 4(a) by keeping only half diagonal spectrum figure 4(c), then an inverse Fourier transform leads to figure 4(d). This result shows that half a spectrum is sufficient to reconstruct an image.

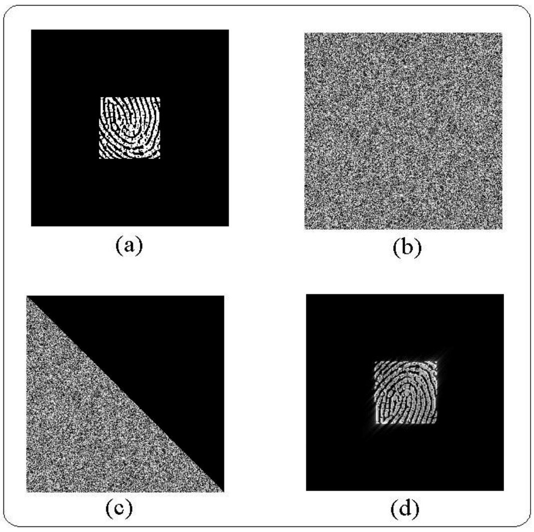


Figure 3 : (a) fingerprint, (b) fingerprint spectrum,(c) half diagonal spectrum, (d) result of the reconstitution

Figure 2 shows that after multiplying the image spectrum by M1, the result, still in the Fourier plane, is multiplied by a second mask of amplitude M2 to select the zones of interest in the last half spectrum. The spectrum of the compressed image is finally obtained at P1, the output plane.

It is worth noting that our compression method is destructive. Indeed, the fact of multiplying the image spectrum by two binary masks of amplitude (1: transmit information, 0: block information) leads to a loss of information. It thus requires to find a compromise between the compression ratio and the quality of the desired reconstituted image.

5. Compression mask manufacturing

The mask of compression, M2, is manufactured by first choosing an image belonging to the type of image we have to compress. The class of concern, here, is a base of several fingerprints. The next step is the selection of an image reference, and of its Fourier transform. The choice of this reference is paramount: it must not belong to the base and determines the compression rate which is related to the degree of similarity between the base and the reference (figure 5). The compression rate increases concomitantly with the degree of similarity.

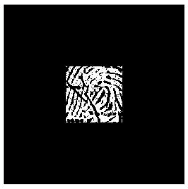


Figure 4 : Image reference: a digital fingerprint

of the same nature as the base to be compressed

At last, for these two spectra, the Fourier plane is segmented into different and independent sub-zones; a white image "1" or a black one is allocated to each of these zones as follows: the first of them is white, the second one black, and so on.

The zones of interest for each of these two images should be carefully chosen and rely on the selection of a good criterion [6].

The among the criteria, we tested the one which seemed to us the most pertinent for our issue was the energy criterion defined as follows [7][8] :

$$\text{Energy creterion} = \frac{\text{Energy of pixel}(\mathrm{i},\mathrm{j})\text{ of the image k spectrum}}{\text{Total energy of image k spectrum}}$$

(2)

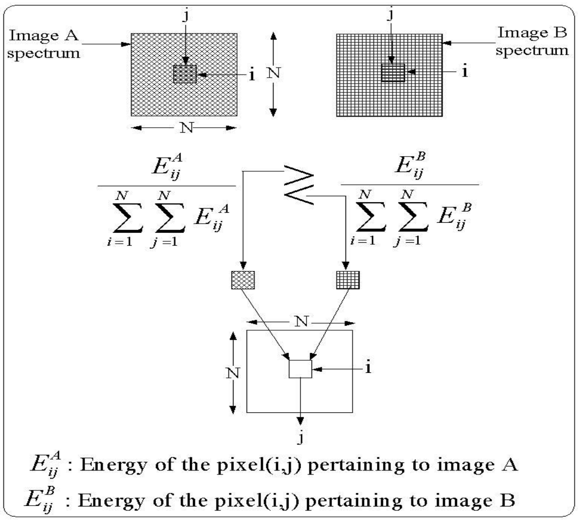


Figure 5 : Segmentation criterion

It shows that, for the two images, the rate of energy for any pixel is related to the total energy of this image in the spectral field. The relationship between these two images has to be compared in order to keep the pixel with the highest energy and build the mask which will be used for compression.

6. Simulation results for compression

The above description highlights the philosophy of all-optical image compression. In order to evaluate the performances of such an architecture, let us consider the fingerprint presented in figure 7(a). To compress it, we will apply the various stages of the method described in the synoptic diagram (figure 2) and start by choosing a reference fingerprint (figure 7(b)) for the segmentation step.

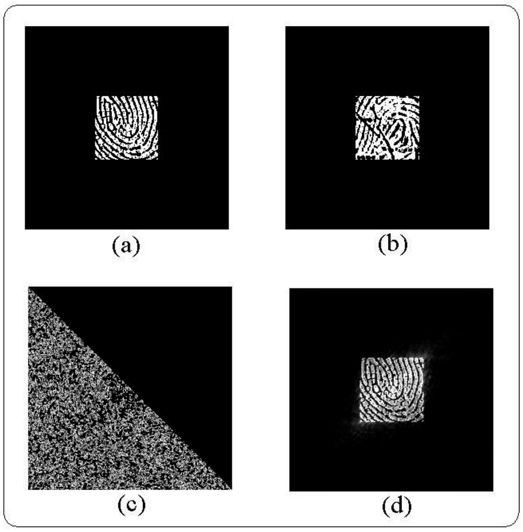


Figure 6 : Optical compression

Figure 7(d) shows the simulation results obtained by using the all-optical compression method and image reconstitution from an inverse Fourier transform of the compressed spectrum.

The efficiency of this method is highlighted since a good-quality target image was reconstituted in the output plane. To assess the performances of our compression method, let us calculate its mean square error given in Eq. (3); it measures the difference between the target image and the reconstituted one.

$$MSE = \frac{1}{N \times N}\sum_{i=1}^{N}\sum_{j=1}^{N}\left|I_d(i,j) - I(i,j)\right|^2 = 0.0846 \qquad (3)$$

where N is the image size(N=256, N^2 pixels, I_d is the reconstituted image and I is the target image.

In our case-study (figure 4(a)), a compression ratio (Eq. (4)) of 87\% corresponds to an error of 0.0846 which exhibits the good performance of this all-optical compression method.

$$\text{Compression ration} = \frac{\text{number of remaining pixel}}{\text{total number of pixel}} \qquad (4)$$

7. Simulation results of both optical compression

Let us now perform the complete procedure, on the following case-study: the aim is to compress the fingerprint displayed in figure 8(a).

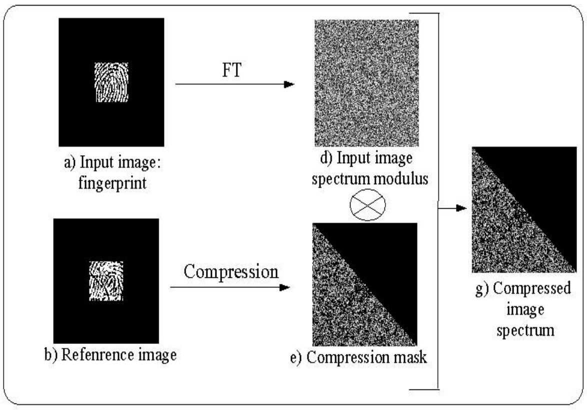


Figure 7 : Simulation results of compression

Figure 8(d) shows the result of the Fourier transformation of this input image in the Fourier plane of the system. Then, to manufacture the compression mask, figure 8(e), a fingerprint is chosen as the reference image to be compressed (figure 8(b)). Figure 9 shows the different degrees reached for image compression by modifying reference image.

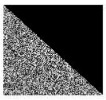
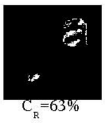
Input image	**Symmetrical mask of amplitude**	**Reconstituted image**	**Image JPEG**
		 C_R=50% Eff=92%; MSE=0,0688	 C_R=50% Eff=77%; MSE=0,0416
Input image	**Reference images**	**Reconstituted image**	**Image JPEG**
		 C_R=63% Eff=79%; MSE=0.0609	 C_R=63% Eff=74%; MSE=0.0409
		 C_R=86% Eff=81%; MSE=0.0794	 C_R=86% Eff=77%; MSE=0.0399
		 C_R=87% Eff=66%; MSE=0.0846	 C_R=87% Eff=77%; MSE=0.0399

Figure 8 : the figure represents the performances of our compression method and the JPEG compression. Were C_R is the compression ratio, Eff is the efficiency and MSE is the mean square error

In order to increase the criteria of performances, we choose the efficiency on reconstruction which is carried out the ratio between the measured intensity in the selected zone (this zone, noted Δ which contains N_Δ pixels, rebuilds the target image) and the intensity measured in the output plane (Eq. (5)) [9][10].

$$Eff\,\% = \frac{\sum_{\Delta} t(i,j)^2}{\sum_{N} t(i,j)^2} \qquad (5)$$

t(i,j) is desired transmittance.

These simulations enabled us to successfully compress and decompress an image with our all-optical method.

In addition, the introduction of the carrier shifted the central reconstituted image of the output plane and caused no reduction of the method performance. This enables us to freely choose a suitable for image reconstitution in order to avoid all noisy zones.

It is worth noting that because of a possible decrease in performance according to the desired compression rate, a compromise between the quality of the reconstituted image and the desired compression rate is required.

8. Conclusion and perspectives

The various simulations results obtained with this new all-optical compression architecture highlight its capability for further optical applications. In addition, it overcomes the problems issued from the use of electronics-based techniques.

Furthermore, the technique of segmentation enabled us to optimise the image spectrum compression by storing only the information relevant for further reconstitution and, therefore, to increase its compression rate. The choice of the reference is paramount because it sets the compression ratio; the latter is related to the degree of resemblance between the base and the reference, and then both are increasing concomitantly. After have presenting the different stages of our method of optical compression, we are now working on the optical implementation of our method.

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