Optical smart packaging to reduce transmitted information

Luisa Cabezas,[1] Myrian Tebaldi,[1,*] John Fredy Barrera,[2] Néstor Bolognini,[1,3] and Roberto Torroba[1]

[1]*Centro de Investigaciones Ópticas (CONICET La Plata-CIC) and UID OPTIMO, Facultad de Ingenieria, Universidad Nacional de La Plata, P.O. Box 3, C.P 1897, La Plata, Argentina*
[2]*Grupo de Óptica y Fotónica, Instituto de Física, Universidad de Antioquia, A.A 1226, Medellín, Colombia*
[3]*Facultad de Ciencias Exactas, Universidad Nacional de La Plata, La Plata, Argentina*
[*]*myrianc@ciop.unlp.edu.ar*

Abstract: We demonstrate a smart image-packaging optical technique that uses what we believe is a new concept to save byte space when transmitting data. The technique supports a large set of images mapped into modulated speckle patterns. Then, they are multiplexed into a single package. This operation results in a substantial decreasing of the final amount of bytes of the package with respect to the amount resulting from the addition of the images without using the method. Besides, there are no requirements on the type of images to be processed. We present results that proof the potentiality of the technique.

OCIS codes: (070.0070) Fourier optics and signal processing; (070.4560) Data processing by optical means.

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1. Introduction

In recent years, the optical community directed its attention to the analysis of multiple data handling [1–4]. The main improvements aimed to the suppression of cross talk among multiplexed data.

We understand that now is compelling to save space resources in transmitting systems. In this context, other approaches were directed towards the reduction in the bytes content sent out. Still and video images are two powerful tools with numerous applications in different sciences. The images are usually digitized and stored for post-detection processing such as image enhancement and feature extraction. When the number of images is usually large, their storage requires the application of image compression. A practical compression scheme is able to recognize accurately the redundant features in an image that is produced under realistic conditions.

Compression techniques have exploited the fact that most image information is contained within only a limited number of frequency components or that real images exhibit fractal properties. Huffman coding [5], an entropy-based technique, is one of the oldest and most widely used compression methods.

Some standards, for example, transport the data representation into the frequency domain by means of the discrete transforms [6]. Transform-based techniques are computationally expensive: the number of operations involved is quadratic to the number of elements to be transformed. A compression algorithm must be computationally simple so that it can be implemented in less-expensive and often less-powerful image-processing systems. Moreover, transform-based techniques pack together the images individually and they are therefore computationally costly when applied to a series of correlated images. The implementation of standards for video images requires powerful image-processing systems, owing to the large amounts of frame processing needed during compression and decompression.

We adopt another quite different strategy to deal with the handling and transmitting of images, conceived in a single package, saving space and preserving their basic characteristics. We base on an image processing, completely within the field of Optics. This processing will generate a new working space. In this framework, our proposal relies in applying a basic 2*f* optical processing scheme to every single image, modulating each one in order to avoid cross talk at the final step, and then multiplexing the entire set of processed images. The multiplexing is probed to have less bytes content than the addition of the whole set of images before the processing mechanism. In this way, we achieve a more compact information-carrying unit. In comparison, our technique does not involve any previous image feature extraction or analysis when applied to image series.

As it is well known, in the 2*f* optical scheme, the input information is transformed into its Fourier components at the back focal plane of the lens. Moreover, if the input object is multiplied (attached) to a random diffuser, we find the convolution of the Fourier transform (FT) of both object and diffuser, giving rise to a distribution like white noise (speckle pattern) [7, 8]. When we want to include different input objects, all stored in the same medium, we speak of a multiplexing procedure. In that case, we face the problem that the wave fronts coming from the storing medium convey the information corresponding to all images thus superposing (cross talking) the information. Several attempts have been done in the conventional multiplexing approach to solve this unavoidable constrain. To overcome this problem, we find in Ref [9, 10]. an adequate conjunction of a multiplexing technique with a pre-modulation approach in a 4*f* scheme that allows removing the problem appearing due to the cross talk. With this issue resolved, it is possible to multiplex successfully in the same medium a number of images. We plan to adopt this method in our approach, in this instance applied to the Fourier plane information of our 2*f* optical system. In this way, we are conducting a new protocol that we call smart packaging.

In the following sections, we present a complete development of the technique and show the results that support our proposal. At the end, we discuss the method and its potentials.

2. Procedure description

A brief description of the procedure follows. First, we select a set of images in a given format (i.e. *.tiff, *.jgp, *.png, etc). We employ the same diffuser for all inputs and a virtual optical system to process every image, by using the 2*f* scheme of Fig. 1(a). If we evaluate the result at the lens Fourier plane, we find the optical convolution described above, which in practice is a speckle pattern. The mathematical expression is given by,

$$\mathrm{P_i}(u,v) = \Im\left[O_{\mathrm{i}}(x,y)\right] \otimes \Im\left[\mathrm{R}(x,y)\right] \tag{1}$$

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where $O_i(x,y)$ represents the image i; $R(x,y)$ is the diffuser; $\otimes$ denotes convolution, $\Im[\ ]$ means the FT operation, and (u,v) are the transforming coordinates of (x,y).

At the same time, we introduce the modulation technique to every processed image. This operation is known as theta-modulation. It consists in placing a sinusoidal grating G_i in contact with the information P_i at the Fourier plane of the lens before multiplexing the sequence of images. Then, each processed output P_i, that is a speckle pattern, is multiplied by a sinusoidal grating G_i with a different orientation and pitch. The resulting multiplexed information $OSP(u,v)$ (see Fig. 1 (b)) is expressed as:

$$OSP(u,v)=\sum_{i=1}^{n}\left(\Im\left[O_i(x,y)\right]\otimes\Im\left[R(x,y)\right]\right)G_i(u,v) \tag{2}$$

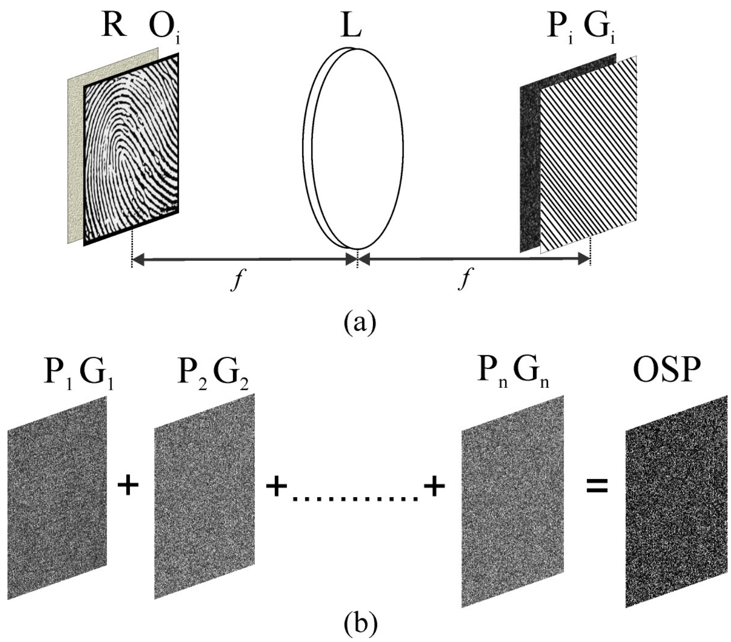

Fig. 1. (a) Optical processing of a single input image: R: random phase mask, O_i: i-th input image; L: lens; *f*: focal length; P_i: i-th Fourier plane image; G_i: i-th sinusoidal grating. (b) Multiplexing procedure to achieve the final OSP.

In this way, during retrieving the theta modulation technique will help in spatially separating the different images avoiding cross talking as schemed in Fig. 2. We observe that all input images are simultaneously recovered at the output plane. In general, this procedure could be extended to not only the grating rotation but also to a simultaneous pitch variation in a way to expand the possibilities to increase the number of modulated images. This multiplexed information is uploaded to the transferring system. We proceed in the following way: if we perform a FT of the multiplexed images, we see paired spots belonging to each modulated image located at different spatial positions according to the pitch and orientation of the modulating grating G_i. Let us filter out all but a given spot to obtain each single image separately. In this way, we isolate each image from the information of the remaining elements of the set. From a practical point of view, the range of pitches and orientations define the upper limit to the amount of processed information without introducing cross talk. Such range is determined by the sizes of both the input images and the filtering plane.

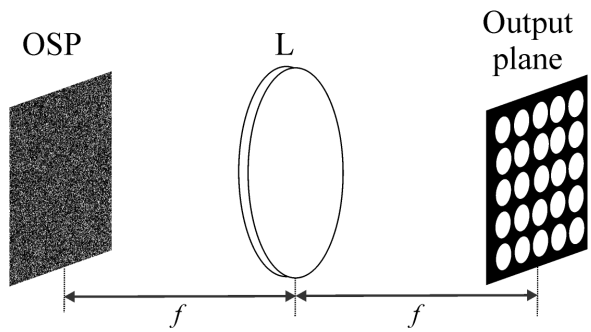

Fig. 2. Fourier transforming of the final OSP from Eq. (2) showing the simultaneous reconstruction of all processed images.

3. Results and discussions

The smart processing resulting from the initial multiplication by the diffuser, the respective FT, the theta modulation and the multiplexing operations, described in the previous section, allow storing several processed images into a single package, resulting in lower byte space content. In our experiment, we take twelve images (see Fig. 3). Each image size is 512 x 512 pixels. The important feature of the images is its weight; therefore, we present only this information in Table 1. The lens involved in the FTs in the virtual optical system has a focal length of 100 mm. The wavelength is 632.8 nm. The resulting area of the output plane is 4096 x 4096 pixels. In our example, we separately distributed the outputs by adequately varying the grating angle in the range between 0° and 153° and the discrete pitches in the range between 5 μm and 12 μm.

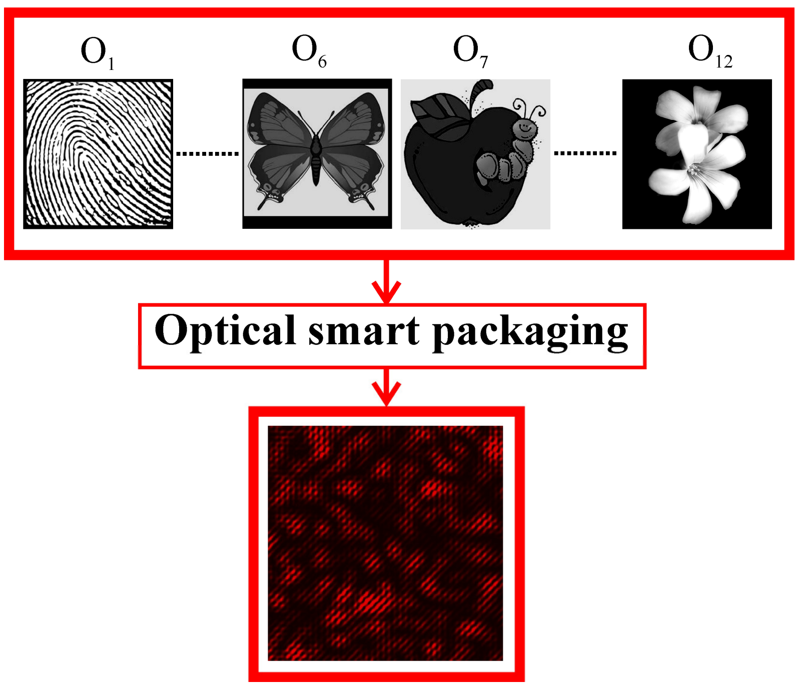

Fig. 3. We scheme the processing for the twelve images case, where we show representative examples in the upper part and in the lower part we show an enlarged portion of the smart package to show the speckle pattern inner modulation.

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Table 1. Image Weights for Different Formats

INPUT IMAGE	TIFF WEIGHT (Kbytes)	JPG WEIGHT (Kbytes)	PNG WEIGHT (Kbytes)
O_1	389,3	128,8	293,7
O_2	198,8	50,9	139,1
O_3	137,1	43,7	133,9
O_4	241,2	40,0	132,2
O_5	473,9	135,3	308,8
O_6	244,8	52,4	144,4
O_7	193,2	43,9	121,8
O_8	241,2	40,3	133,1
O_9	476,4	136,4	312,7
O_{10}	229,5	52,4	139,0
O_{11}	192,6	43,9	119,7
O_{12}	231,1	40,3	126,7

Table 2. Set Weights for Different Image Formats [a]

	TIFF		JPG		PNG	
Image set	**Set weight (Kbytes)**	**OSP weight (Kbytes)**	**Set weight (Kbytes)**	**OSP weight (Kbytes)**	**Set weight (Kbytes)**	**OSP weight (Kbytes)**
$\mathbf{O_1}$	389,9	307,1	128,8	85,2	293,7	265,0
$\mathbf{O_1,O_2}$	588,0	317,8	179,7	90,3	432,7	270,4
$\mathbf{O_1,O_2,O_3}$	725,1	320,2	223,4	91,8	566,6	271,5
$\mathbf{O_1,\ldots,O_4}$	966,3	323,2	263,3	93,6	698,8	274,2
$\mathbf{O_1,\ldots,O_5}$	1440,2	324,9	398,6	95,1	1007,6	277,2
$\mathbf{O_1,\ldots,O_6}$	1685,0	325,1	451,0	97,4	1152,0	277,9
$\mathbf{O_1,\ldots,O_7}$	1878,2	327,0	494,8	99,4	1273,8	279,0
$\mathbf{O_1,\ldots,O_8}$	2119,3	328,1	535,1	101,4	1406,9	279,5
$\mathbf{O_1,\ldots,O_9}$	2595,7	332,4	671,6	102,8	1719,6	280,1
$\mathbf{O_1,\ldots,O_{10}}$	2825,2	334,8	724,0	105,4	1858,6	280,5
$\mathbf{O_1,\ldots,O_{11}}$	3017,8	340,3	767,9	106,7	1978,3	281,1
$\mathbf{O_1,\ldots,O_{12}}$	3249,0	345,2	808,2	111,0	2105,0	282,0

[a] Each row represents a given set of images and their corresponding weight is shown in the first column for the selected formats. The resulting OSP weight for every set is also shown in the second column for the corresponding format.

It should be pointed out that the multiplexing operation of several processed and modulated images into a single package appreciably reduce the final amount of bytes as can be confirmed by observing the results of Table 2. The results correspond to the well established image formats: *.tiff, *.jpg and *.png. We transmit to the final user the package containing the multiplexed information as depicted in the second column of Table 2 for every format. The essential result to be highlighted is that the procedure allows reducing the information to be transmitted.

In our example, the lower row shows the twelve images case. In particular, referring to the *.jpg format, where the final OSP weight is approximately ten times lower than the sole addition of the same twelve *.jpg images. This result clearly shows the byte weight reduction ability played by the proposed optical protocol. No matter the format selected, we always find a significant reduction factor, which is even more important as we increase the number of multiplexed images.

Fig. 4. Four recovered images out from a package containing twelve inputs showing no traces of cross talk among them.

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It is important to remark that the introduction of the modulation gratings ensures that cross talk is fully avoided by an appropriate selection of the modulation parameters (pitch and orientation) Fig. 4 shows four recovered outputs showing no traces of other images, demonstrating zero cross talk.

It is important to remark that the discussion is completely based on virtual optics concepts. In this context, we must pay attention to the fact that an upper limit should be set to the number of images that can be multiplexed. This upper limit is imposed by the geometry of the optical system as well as the possible rotation angles and pitches variation that can be solved by the procedure. Further research in this regard is in progress.

Transform coding, such as the Fourier transform decomposes an image into its spectral components. One can achieve data reduction by appropriately coding the spectral components. This process is accomplished in the $2f$ architecture. The optical handling also provides a parallelism not found in other non-optical methods. The method is far more flexible while not restricting any kind of images to be processed.

Summarizing, we present a new development for image packaging that reduces the amount of information transmitted to a final user showing a new approach completely based on the optical domain opening a new vision regarding information handling. The method consists in an image processing and multiplexing, and a corresponding recovering procedure to visualize the original inputs. We compare different image standards to our technique to sustain the concept.

In this sense, we propose a new optical procedure, namely Optical Smart Packaging (OSP), for the protocol developed in this contribution. We are aware that further research must be developed in connection with different aspects of this new protocol, but we think that the novelty itself worth communicating.

It is important to emphasize that this contribution renew the role of optics in the techniques for information and communication, which indeed validates the impact that still have on future applications in this sense.

We want to present this finding in the hope to open a window to inspire further research into a deeper understanding of the introduced facts.

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