A Natural Image Compression Approach Based on Independent Component Analysis and Visual Saliency Detection

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In this paper, a natural image compression method is proposed based on independent component analysis (ICA) and visual saliency detection. The proposed compression method learns basis functions trained from data using ICA to transform the image at first; and then sets percentage of the zero coefficient number in the total transforming coefficients. After that, transforming coefficients are sparser which indicates further improving of compression ratio. Next, the compression method performance is compared with the discrete cosine transform (DCT). Evaluation through both the usual PSNR and Structural Similarity Index (SSIM) measurements showed that proposed compression method is more robust than DCT. And finally, we proposed a visual saliency detection method to detect automatically the important region of image which is not or lowly compressed while the other regions are highly compressed. Experiment shows that the method can guarantee the quality of important region effectively.

Keywords: ICA, DCT, Visual Saliency Detection, Compression.

1. INTRODUCTION

Independent component analysis (ICA) considers a class of probabilistic generative models in which an observed random vector \( X \) can be expressed as:

\[
X = AS
\]

where \( A \) is a mixing matrix and \( S \) is a vector of containing independent sources.1 This model can be applied to the grayscale values of images, each sample of \( X \) usually contains the pixels in an image block.

It has already been indicated that images of natural scenes are well modeled when the columns of \( A \), which can be seen as a basis bank of wavelet-like filters, and the independent sources have heavy-tailed distributions.1 That is to say, with high probability, only a small fraction of the elements of \( S \) have significant values; this sparse nature of \( S \) indicates the possibility of using overcomplete ICA to compression and denoising of natural images.1 In Refs. [2, 3], the problem of using ICA for image compression is addressed. The authors of literature (Refs. [2, 3]) have presented ICA based image compression system and got a promising performance.

In this paper, we use the FastICA algorithm1,4 to learn basis vectors from sets of training images and improve the compression ratio by enhancing the sparse nature of the independent components.6 Besides, we proposed a visual saliency detection method which is used to detect the saliency region. And the quality of this region is guaranteed during the other regions are highly compressed.

The paper is organized as follows. Section 2 describes the proposed method based on ICA. In Section 3, we propose the framework of our saliency detection method. Experimental results are reported in Section 4, and the last section is devoted to conclusions.

2. ICA FOR NATURAL IMAGE COMPRESSION

In summary, the outline of the natural image compression approach presented in this paper is illustrated in Figure 1. It involves six steps.5 (1) Learning ICA basis vectors from the training images by applying FastICA. (2) Calculating the inverse or pseudo inverse of bases matrix, we call the obtained matrix \( W \). (3) Preprocessing the image which is to be compressed. First, we divide the image into small square blocks (\( 8 \times 8 \)). Each block is a column of matrix \( X \). Then, we subtract local mean and reduce the dimensionality by Principal Component Analysis (PCA). At last, we obtained matrix \( X \). (4) Obtaining the independent sources \( S \) according to:

\[
S = WX
\]
Training images

Test images

Learn ICA basis vectors by FastICA

Divide into square blocks

Calculate inverse or pseudo inverse of basis vectors

Subtract local mean

Reduce dimensionality by PCA

Obtain the independence sources

Set zero coefficient percentage

Use run length encoding to encode

Reconstruct the images

Fig. 1. The framework of the proposed approach based on ICA.

where $W$ and $X$ are obtained by step (2) and step (3) respectively. (5) Setting zero coefficient percentage. Only the elements with significant values are reserved while others are set to zero. After that, we get new independent sources $S^*$. Finally, we use Run Length Encoding method to encode $S^*$. (6) Reconstructing the image $X^*$ according to:

$$X^* = AS^* + E(X^0)$$

3. THE SALIENCY MEASUREMENT

The saliency measurement used in our method is shown in Figure 2. There are three main steps in saliency detection: representing image patches, reducing dimensionality and evaluating the spatially-weighted dissimilarity. Non-overlapping patches drawn from an image are represented as vectors of pixels. All patches are mapped into a reduced dimensional space. And then the saliency of each image patch is determined by aggregating the spatially-weighted dissimilarities between this patch and all the other ones in the image. In Figure 2, all patches are reduced to 3 dimensions for a better illustration; in fact, it can be arbitrary dimensions in practice. The weighting mechanism indicating central bias is used in next step. Finally, the saliency map is normalized and resized to the scale of the original image, and then is smoothed with a Gaussian filter ($\sigma = 3$). And the interested reader is encouraged to consult 6 for more details.

4. EXPERIMENTAL DETAILS

According to the proposed framework mentioned in Sections 2 and 3, our experiments including two classes. One class of experiments is based on ICA; the other is based ICA and visual saliency detection. However, there is a common step named basis functions extraction in these experiments. So we first introduce the basis functions extraction, then we compared the two class experiments. During the basis functions extraction, we choose 10 images which can be obtained from the website.5 50000 sub-windows are extracted from these images by using $8 \times 8$ sliding window, which makes up of a $64 \times 50000$ training data set. After mean removal and whitening by principal component analysis,
we get a $40 \times 50000$ data set $X$. Then we apply the FastICA algorithm to learn basis for this data set $X$. Figure 3 demonstrates these 40 basis functions. We can discover that ICA basis functions possess location, orientation and frequency selective properties. Then, these basis functions are used to the two class compression experiments. The details of these two class experiments are described in Sections 4.1 and 4.2 respectively.

4.1. Experiments Based on ICA

To evaluate the performance of proposed framework mentioned in Section 2, we have compressed two images (not used in the learning set) for ICA and DCT. Then, the compressed images were compared using Peak Signal-Noise-Ratio (PSNR) and Structural Similarity Index (SSIM) measurements respectively. PSNR is an objective measurement based on mean squared error (MSE) which has a visual metric as discussed in Ref. [7]. To overcome the drawback of PSNR, SSIM is adopted. It takes into account the retention of the original structure when evaluating a distorted version.

<table>
<thead>
<tr>
<th>Zero coefficient percentage (%)</th>
<th>PSNR</th>
<th>SSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insect image</td>
<td>Mountain image</td>
</tr>
<tr>
<td>70</td>
<td>29.363</td>
<td>27.374</td>
</tr>
</tbody>
</table>

Table I. Values of PSNR for reconstructed images.

<table>
<thead>
<tr>
<th>Zero coefficient percentage (%)</th>
<th>SSIM</th>
<th>Insect image</th>
<th>Mountain image</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.834</td>
<td>0.837</td>
<td>0.812</td>
</tr>
<tr>
<td>80</td>
<td>0.685</td>
<td>0.753</td>
<td>0.651</td>
</tr>
<tr>
<td>90</td>
<td>0.433</td>
<td>0.634</td>
<td>0.388</td>
</tr>
<tr>
<td>99</td>
<td>0.089</td>
<td>0.444</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Table II. Values of SSIM for reconstructed images.

![Fig. 5](image1) ![Fig. 6](image2)

**Fig. 5.** Reconstructed images for DCT and ICA. The zero coefficient percentage is set as 90%, 96% and 99%.

**Fig. 6.** Saliency Detection results on the insect image. (a) is obtained by our saliency detection method and (b) is got by converting image (a) to binary image.
In Section 4.1, every region of test image is compressed with the same ratio. Actually, some regions of an image are important while other regions are not. It is not reasonable if the same compression ratio is used to these different regions. So the compression ratios of the important regions should be low and other regions should be highly compressed. It not only can improve the compression ratio but also can guarantee the quality of important regions. However, to solve this problem, the most important thing is to judge automatically whether a region is important. We introduce a visual saliency detection measurement which is depicted in Section 3 to detect the important region of image automatically. Figure 6 shows the saliency detection results on insect image. We can find that the proposed method can successfully detect the important region (the head of the insect). And Figure 7 demonstrates the reconstructed results after using saliency detection method. The zero coefficient percentage of regions which are unimportant are kept at 90%, 96% and 99% respectively while the important regions are not compressed. Compared (a), (b) and (c) in Figure 7 with (b), (d) and (f) in Figure 5, we can find that the quality of the three images in Figure 7 is better than that of three images in Figure 5 obviously. And the important regions of images in Figure 7 are still clear though the unimportant regions are blurred. So, it can be claimed that the presented method can guarantee the quality of important region effectively.

5. CONCLUSIONS

We have proposed a natural image compression method based on the ICA and visual saliency detection. The sparse nature of the independent components was successfully used to compress images. This method was compared with DCT through PSNR and SSIM measurements. The results showed our method is more robust to distortions than DCT. The saliency detection method can successfully detect the important region and when it was used to the compression, the quality of important region was guaranteed effectively.

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References and Notes