영상 압축 센싱을 위한 하이브리드 센싱 행렬 연구

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Study on hybrid sensing matrix for compressive sensing of images

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요 약

Compressive sensing is a new sampling technique, which allows to sample a signal under the Nyquist-Shannon sampling rate. For block-based compressive sensing, a hybrid sensing matrix which contains low-frequency patterns in addition to the random Gaussian numbers is good for exploiting typical property of natural images. By noting that MH-BCS-SPL is well known for its good recovery performance, this paper investigates effect of the hybrid sensing matrix on MH-BCS-SPL in the sense of how large portion of low-frequency patterns can provide performance improvement.

1. Introduction

In recent years, a new sampling technique named as compressive sensing (CS) [1,2] has emerged and rapidly attracted much attention. In CS theory, a signal x with length N can be exactly reconstructed from small number of M measurements (where $M << N$) if x is K-sparse (i.e., x has at most K, where $K < N$, non-zero coefficients) or compressible. A measurement vector y of the signal x is obtained by using a sensing matrix Φ as follows:

$$y = \Phi x = \Phi \Psi s \,, \tag{1}$$

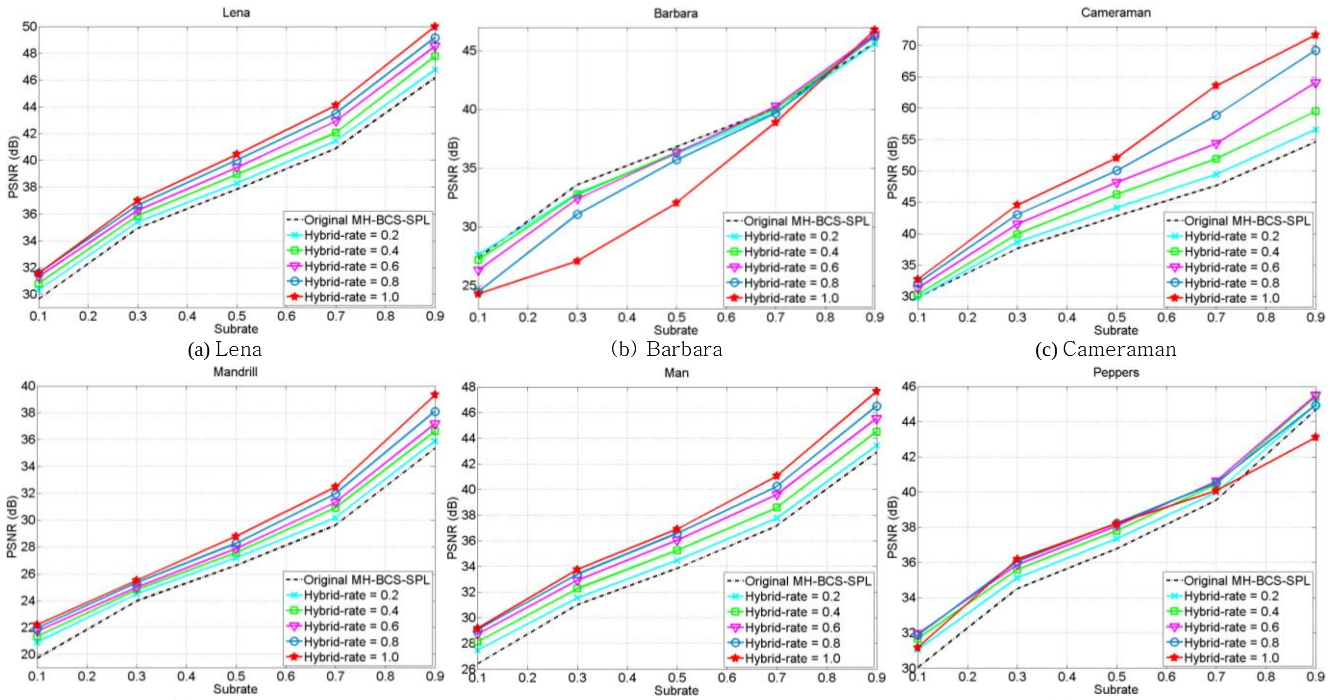
where s is a sparse representation of the signal x in a proper sparsifying transform Ψ as $x = \Psi s$. The ratio M / N is called sub-rate. Owning to lower sampling rate, CS has drawn so much attention to see quite a number of CS recovery methods proposed [2]. Among them, the MH-BCS-SPL (multihypothesis prediction and residual reconstruction, mutihypothesis block compressed sensing with smoothed projected Landweber) [3] is known to have good recovery performance. However, it uses a random Gaussian matrix which does not consider the property of natural images. Note that, most likely, a natural image has most of its energy concentrated on a few low-frequency coefficients. Therefore, studies on exploiting the property in sensing matrix design by using a proper transform kernel were made for magnetic resonance imaging [4] and CS of images [5]. Furthermore, Discrete Cosine Transform (DCT) is known to have good energy packing efficiency and low complexity (its data-independence). Therefore, this paper investigates hybrid sensing matrix with DCT kernel on MH-BCS-SPL. The combination of hybrid sensing and MH-BCS-SPL is expected to improve performance of block-based CS of images. However, how large the portion of low-frequency patterns should be is yet to be studied thoroughly with respect to CS performance.

2. MH-BCS-SPL

In a block-based CS, an original image is divided into small blocks of size $B \times B$; each block is then sensed using a Gaussian random matrix Φ to generate its measurements. It is remarked that block-based CS of natural images is a practical solution due to its less requirement of memory for storing the sensing matrix. At the recovery, in per iteration, the Tikhonov regularization predicts an initial reconstructed image. Following, details with low contrast are recovered from the difference between (received) measurement of original image and that of the initial reconstruction. MH-BCS-SPL manifests good performance in terms of preserving detail of images.

3. Hybrid sensing matrix

For block-based sensing in CS, most of techniques acquire the signal using Gaussian random matrix. Thus, all of the measurements have equal importance, however, the property of images is not appropriately considered. Note that, in a specific transform domain (*e.g.,* DCT), the energy of natural image mostly concentrates on a few coefficients at low frequency positions. The study in [5] proposed a form of sensing matrix utilizing the structure of image for single pixel camera. The sensing matrix contains two subsets in a form of $\Phi = [\Phi_s \quad \Phi_r]^T$, where Φ_s is low-frequency patterns and Φ_r is random projection. The Φ_s can be generated from a direct transform (i.e., DCT) or pre-learned by using principal component analysis from a set of training images whereas entries of the random pattern are typically drawn from Gaussian random matrix. If the low-frequency part is set to follow DCT patterns, its rows come from first few DCT bases in zigzag order. By using such a hybrid matrix, the measurement vector of image is expected to contain prior information on image.



(a) Lena (b) Barbara (c) Cameraman

(e) Mandrill (f) Man (g) Peppers

Fig. 1 The PSNR of study method compared to the original MH-BCS-SPL algorithm

By using such a hybrid matrix, the measurement vector of image is expected to contain prior information on image. We call the ratio of the number of DCT measurements to the total number of measurements as hybrid-rate.

4. Experimental results

We investigate the effect of the hybrid-rate when the hybrid sensing matrix is employed for MH-BCS-SPL using six 512x512 grayscale images (i.e., Lena, Barbara, Cameraman, Mandrill, Peppers, and Man), which have various properties (i.e., smooth and detail). Block size is 32x32; sub-rate is from 0.1 to 0.9; and the hybrid-rate is from 0.0 to 1.0.

Fig. 1 shows the PSNR of the hybrid sensing and the conventional MH-BCS-SPL. We can observe that, mostly, the hybrid sensing provides better CS performance. On example of a very smooth image like Cameraman, the performance of hybrid sensing is much better, by about more than 5dB compared to conventional MH-BCS-SPL. Especially at high subrate of 0.9, the hybrid-rate 1.0 provides 17dB gain. However, with Barbara which contains much texture and fine details and or which DCT kernel cannot represent its energy with a small number of low-frequency coefficients in zigzag-scanned order, the hybrid sensing degrades quality of recovered Barbara.

5. Conclusions

This paper investigated the hybrid sensing, which contains low-frequency DCT bases in addition to random projection, used for MH-BCS-SPL. Experimental results confirmed that, for most of test images, the hybrid sensing helps extracting most signal energy well resulting in better CS performance. However, there are still some cases, for example, images with lot of texture like Barbara, the hybrid sensing even degrades its recovery. Therefore, our next step is to study on hybrid sensing adaptively used with respect to the property of input images.

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