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Random small probability sample matrix used in compressed sensing imaging

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Abstract

This investigation aimed to one common key issue of the two imaging types, the sampling of the template configuration. A first selector framework that employs *MATLAB* to perform attractive features of the small probability matrices in random sampling matrix from Gaussian random matrix was presented. Gaussian random matrix is usually used as random sampling matrix in Single Pixel Camera. The small probability matrices in random sampling matrix can obtain a recovery image of higher accuracy for singe detector imaging system and detector array imaging system.

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Keywords: sampling template; compressed sensing; random matrix selector; flexible electronic device; inspection

1. Introduction

In the single detector imaging system with multi-channel and high flux, such as emerging single pixel camera imaging system [1] and Hadamard Transform Optics [2], tow basic subsystems, which are sampling template and recovery, always exist. The sampling template and recovery of single pixel camera completely dependent on compressed sensing[3] method. Single Pixel Camera has the ability to obtain an image with a single detection element and collecting the number of image that are fewer than image pixels, relying on suitable sampling template and recovery method. It provides a thoroughfare for manufacturing of inspection and measurement, especially for the flexible electronic device. The inspection and measurement of flexible electronic device always need imaging some micro-constructs hidden under the opaque polymer substance, which can be penetrated by THz wave. And therefore, a THz super-resolution imaging system is an important equipment for the inspection and measurement of flexible electronic device, while a suitable sampling template is exactly necessary for this THz super-resolution imaging system. In this paper aiming at the sampling template configuration (sampling matrix), a small probability matrix of binary random matrix and its selector was proposed and demonstrated.

Compressed sensing, which breaks through the classical law of Nyquist sample, aims to recover a sparse image signal x from under sampled indirect measurements $y = Ax \in X^{nxN}(n \le N)$. Then, x is expressed as $x = \Psi s$ with another sparse transform base $\Psi = \{\Psi_1, \Psi_2, ..., \Psi_N\}$. To solve the equations under defined namely NP-hard problem [4, 5], s can be estimated by convex optimization $\min\|s\|_1$:

$$\arg\min\|s\|_1 \; s.t. \; y = A\Psi s \qquad [1]$$

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So, the main research contents in compressed sensing are about how to construct a sample matrix *A* and solve Eq **1** accurately or the most approximately. Candes, Romberg and Tao et al demonstrated that, the sensing matrix $\Theta = A\Psi$ satisfying the conditions of restricted isometric property (RIP) [6] is the guarantee of signal recovery:

$$(1-\delta)\|s\|_2^2 \le \|A\Psi s\|_2^2 \le (1+\delta)\|s\|_2^2$$
[2]

In actuality, it is difficult to use RIP to instruct the design of the sample matrix. The equivalent condition of RIP presented by Baraniuk [7] is that the sample matrix *A* is irrelevant to sparse transform base Ψ and Gaussian random matrix has little coherence of most of the sparse transform base Ψ in order to satisfy the constraints preferably, which is usually used as sampling matrix in compressed sensing [8,9].

David L. Donoho，Hatef Monajemi et al investigated the concept of deterministic matrix[10]. Now, a series of small probability matrices in random sampling matrix from Gaussian random matrix are studied to realize THz imaging [11] or wide-field super-resolution optical imaging.[12-13] The super-resolution optical imaging is based on the sub-wavelength hole arrays with extraordinary optical transmission (EOT) [14-15].

2. Method

2.1. The inevitability of small probability events

In the classical probability statistics, a small probability event can be defined as an event owning low probability ($p < 0.05$). It is almost impossible to happen in one trial. Assuming that, the probability of a small probability event *A* is ($\varepsilon < 0.05$), then $\overline{A}(1-\varepsilon)$. *B* can be defined as the event that *A* doesn't happen at all in n trials, so the probability of *B* is $(1-\varepsilon)^n$. Therefore, the probability of $\overline{B}$ occurring at least once in n trails is as follows:

$$P = 1-(1-\varepsilon)^n$$
[3]

$P \to 1$ as $n \to \infty$, thus $\overline{B}$ namely the occurring of small probability event *A* will always be carried out in the constant independent trails. The transformation theorem of random events [16] presented by Ke-qin Zhao indicates that, if the event *A* occurred at the *K*-th test for the first time in the frequency-type random trial *E* (*n* is large enough), the event $\overline{A}$ will definitely happen at the $(K+m)-th$. Eq **3** attests that a small probability event of almost impossible occurrence is bound to happen, which aligns with the transformation theorem of random events.

There exists a small probability matrix in the random sampling matrix to obtain a better recovery image.

2.2. The small probability matrix

In our study, the small probability matrix in binary random matrices mainly includes a selected binary matrix by the random matrix selector.

The random matrix selector with *MATLAB* software is designed. The function of the selector is to search a better binary random structure and obtain a preferable recovery by generating various random structures.

2.3. Random matrix selector

A random matrix selector module whose function is to select the random binary matrix using in compressed sensing is designed by *MATLAB*. A random binary matrix is generated , then to select better random binary matrix, and the recovery image is obtained by the gradient projection for sparse reconstruction (GPSR).

In the experiments, the random matrix selector is used to generate thousands of different binary random matrices, and compute the peak signal to noise ratio (PSNR) of the image reconstructed by each sampling matrix. Owning the best performance, the first 18 matrices are shown in Fig 1. Based on the result above, the random matrix selector can be thought as an excellent method to search some preferable properties of sampling matrix.

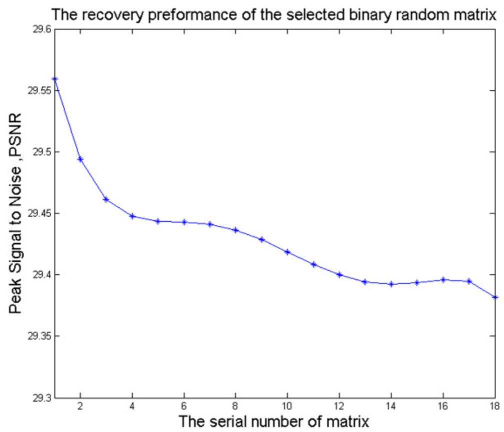

Fig. 1. The recovery performance of the selected binary random matrix.

2.4. Two kinds of recovery algorithms and the sampling mode

Using the GPSR [17] in convex optimization algorithm and the orthogonal matching pursuit (OMP) [18] in greedy algorithm, it can be recovered that the sparse image signal *x* respectively.

The sampling mode of OMP and GPSR is briefly described in Two imaging mode.

- The imaging mode of GPSR.

The measurements $y = A.*x$ are obtained by means of matrix dot product (multiplying the corresponding element) in