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Noise reduction in selective computational ghost imaging using genetic algorithm

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ABSTRACT

Recently, we have presented a selective computational ghost imaging (SCGI) method as an advanced technique for enhancing the security level of the encrypted ghost images. In this paper, we propose a modified method to improve the ghost image quality reconstructed by SCGI technique. The method is based on background subtraction using genetic algorithm (GA) which eliminates background noise and gives background-free ghost images. Analyzing the universal image quality index by using experimental data proves the advantage of this modification method. In particular, the calculated value of the image quality index for modified SCGI over 4225 realization shows an 11 times improvement with respect to SCGI technique. This improvement is 20 times in comparison to conventional CGI technique.

1. Introduction

Ghost imaging (GI) is a novel correlated-photon imaging technique. The most considerable advantage of this method is non-requirement of putting the object in front of the imaging sensors. Common GI method follows using two highly correlated optical beams; one beam interacts with an object and then collected by a single-pixel output detector, termed the bucket detector. Another beam instead of striking the object impinges on a high-resolution (multiple-pixel) detector mostly a kind of imaging sensors like: Charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS). The cross-correlation between two optical beams results ghost image [1–10]. Ghost imaging is performed originally by using orthogonally polarized idler and signal beams produced by spontaneous parametric down conversion (SPDC) process [11]. Subsequent theory and experiments demonstrated in GI, consideration of quantum viewpoint and photon's entanglement are not mandatory. Thus, the GI can be performed with a classical (thermal or pseudo-thermal) light source by considering the classical light correlation [12–14]. In traditional GI with thermal light, a spatially incoherent beam, which is produced by linear propagation of laser light through rotating ground-glass, is separated to the signal and reference arms. It has been shown that computational ghost imaging is easier and has higher speed operation than other configurations [15,16]. By implementing a spatial light modulator (SLM) to generate a random pattern, in computational ghost imaging (CGI), we can easily replace the reference arm with numerical computations and there is no need for the beam splitter and a multiple-pixel detector. Recently the 3D form of CGI has performed that uses several single-pixel detectors in different locations [17].

The most considerable difference between quantum ghost imaging and classical ghost imaging is the matter of visibility. The biphoton ghost image can achieve 100% visibility, but there is a background level or noise in pseudo-thermal ghost image [18]. Many different techniques have been proposed to overcome this limitation and improve pseudo-thermal ghost image quality [19–24] (e.g. compressive GI, differential GI and normalized GI). Compressive GI [19] uses an algorithm based on compressed sensing that reduces the number of realizations required for ghost image reconstruction. The imaging of weakly absorbing objects is possible by differential GI [20] and measuring the transmission function of an object in absolute units. In normalized GI [21], a normalized weighting algorithm is used to improve image quality.

Recently, we have introduced selective computational ghost imaging (SCGI) as a new technique which enables the reconstruction of an N-pixel image from N measurements or less [25]; this technique has a great advantage on optical encryption. In this paper, we propose a novel method to modify and improve image quality reconstructed by SCGI technique that we name it “modified selective computational ghost imaging (MSCGI)”. In addition to the conventional methods for improving ghost image quality, in this work, we used a genetic algorithm as an optimization method to reduce background noise in SCGI. To evaluate the performance of MSCGI, we analyzed a new image quality parameter namely the universal image quality index.

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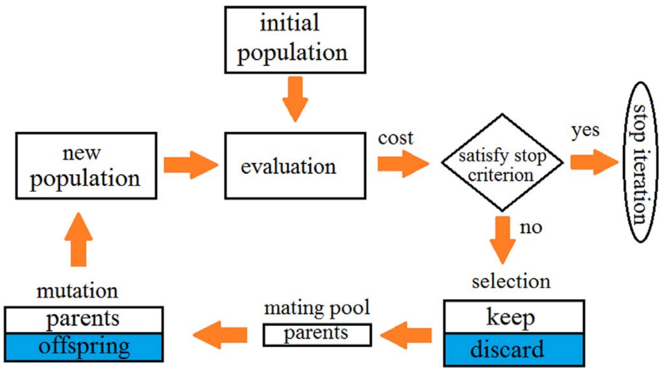

Fig. 1. Genetic algorithm flowchart.

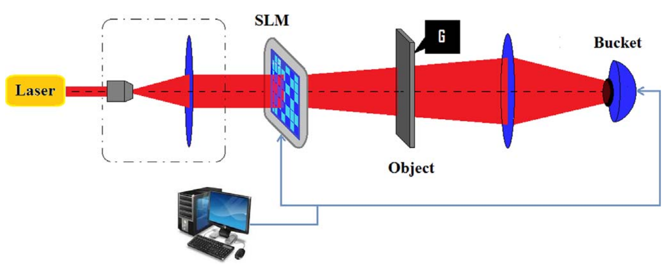

Fig. 2. Experimental setup of computational ghost imaging.

2. Selective computational ghost imaging (SCGI)

In CGI by computing cross-correlation between known intensity pattern at the object plane, $I_i = |E_i(x, y, z = L)|^2$, and measured intensities of bucket detector $B_i = \int dxdy I_i(x, y, L)T(x, y)$, ghost image can be retrieved:

$$G(x, y) = \frac{1}{N}\sum_{i=1}^{N}(B_i - \langle B\rangle)I_i(x, y) = \langle BI(x, y)\rangle - \langle B\rangle\langle I(x, y)\rangle \tag{1}$$

In conventional computational ghost imaging (CCGI), speckle patterns applied to the SLM in the form of random matrices. So, each array of the matrix attributes to one random value as an intensity modulator. Consequently, in every realization, each matrix array will be a random value. Similarly, in SCGI method, in each realization, we consider a random matrix as an intensity modulator to establish on the

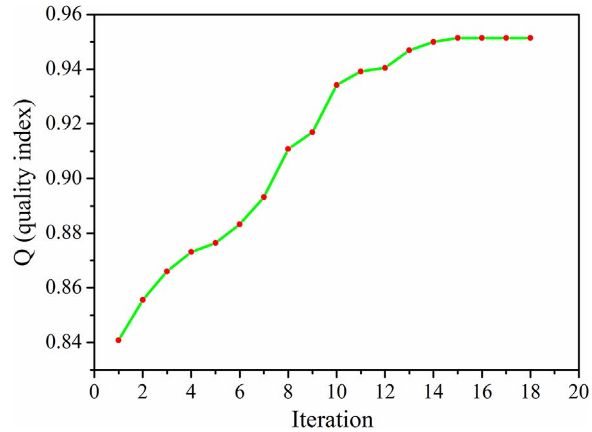

Fig. 4. Calculated quality index in each iteration by genetic algorithm.

SLM, but one arbitrary element of it attributes to a different value that is much larger than others in a way that the transmitted intensity from this element will be much greater than the other elements [25]. Since in each realization one and only one element of the matrix attributes to a different value, in the total iterations, each element takes a different value just once. Accordingly, the maximum realization required for reconstructing images with the best quality is equal to multiplying the matrix's number of rows and columns; in other words, N is equal to the size of $I(x, y)$. Thus, SCGI has the capability of reconstructing an N-pixel image from M measurements where $M \leqslant N$.

3. Genetic algorithm (GA)

Genetic algorithm (GA), which is known as a random optimization method, was invented by John Holland in the 1970s [26]. GA is based on Darwin's theory of gradual evolution. For developing the solutions of an optimization problem, the algorithm uses the same principles that nature implement on the evolution of gene symbols [27–30]. A common method used to implement the genetic algorithm is as the following:

- A set of random solutions, which are called populations, are generated.
- In each iteration, all solutions are evaluated using a fitness function. Then, some of the best solutions are selected using a probability

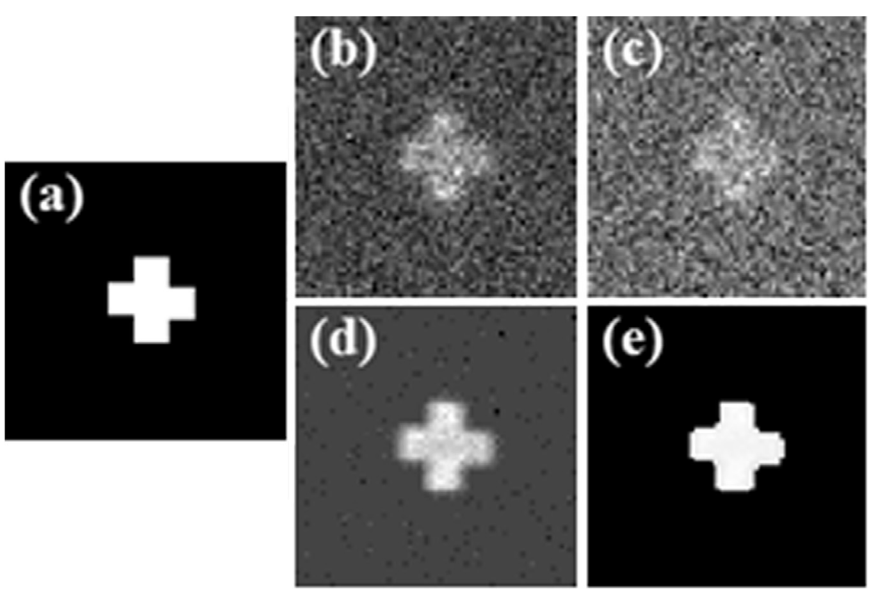

Fig. 3. Experimentally reconstructed ghost images with size 65×65 pixel from 4225 realization. (a) Original slide (b) CCGI (c) MCCGI (d) SCGI and (e) MSCGI.