Methods of compression of digital holograms, based on 1-level wavelet transform

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Abstract. To reduce the size of memory required for storing information about 3D-scenes and to decrease the rate of hologram transmission, digital hologram compression can be used. Compression of digital holograms by wavelet transforms is among most powerful methods. In the paper the most popular wavelet transforms are considered and applied to the digital hologram compression. Obtained values of reconstruction quality and hologram's diffraction efficiencies are compared.

1. Introduction

The photography allows to register amplitude (intensity) of the waves. In result information about objects can be retrieved in 2D-form [1-2].In the same time the holography allows to obtain information about object in 3D-form [3-7]. As a result now digital and computer holography are popular techniques in different fields of scientific research: an interferometry [8-9], microscopy [10-11], optical and optoelectronic information processing [3, 12], reconstruction static and dynamic 2D- and 3D-scenes [13-16], and etc.

Characteristics of digital photo- and videocameras are improving. Currently size of images may be more than ten megabytes [17-18]. For transfer of holographic video with a standard frequency of movies (24 Hz) it is necessary to have the channel with capacity of 2-4 Gbit/sec. This size is significantly more, than in standard communication channels. Size of ten minutes of holographic video will be more than 1 terabyte. Thus large archival memory sizes are required to store holographic video.

To compress digital and computer-synthesized holograms, various types of compression methods [19-24], including methods based on different transforms (cosine, wavelet, etc.) are used. In case of compression of standard photoimages, this group of methods allows to reach high compression ratios with the minimum losses of quality [25-27]. Compression on the basis of wavelet transform consists in decomposition of the initial photoimage on arrays of the approximating coefficients and the related coefficients of specification. These coefficients allow to consider dependences between values of a signal (intensity) in the next pixels.

In this paper the most popular methods of wavelet compression of digital holograms are considered and applied.

2. Application of wavelet transforms for digital holograms compression

The described approach of images compression is focused on digital processing with gradient of brightness since it is possible to describe gradient of brightness by small number of coefficients. Thus, in case of compression of standard photos, high compression ratios (up to 200-300 times) with the minimum losses of quality or even without quality loss are achieved.
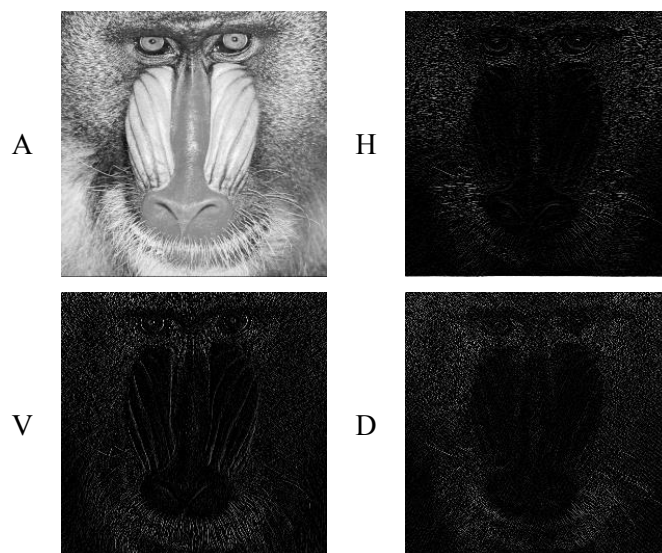

Figure 1. Wavelet transform of standard grayscale image: approximating (A), horizontal (H), vertical (V) and diagonal (D) coefficients of decomposition

However holograms are actually interference patterns with a large number of small details with different brightness. Such images are described by a large number of the approximating coefficients. Thus, the methods based on wavelet transforms provide smaller compression ratios for holograms, than that one for standard photos. However, despite focus of a method on compression of images with gradient of brightness, it is possible to choose the wavelet transform considering features of a certain type of images as in case of digital holograms.

Wavelet transform coefficients of decomposition of standard grayscale image are shown in Fig. 1 and coefficients of decomposition of digital hologram are shown in Fig. 2.

There are different types of wavelet transforms [25-27]:
- orthogonal,
- semi-orthogonal,
- biorthogonal,
- symmetric,
- asymmetric,
- and etc.

Also wavelet transforms differ with smoothness degree, range of definition, computer resource intensity. In practice it is necessary to choose the wavelet transforms having algorithms of fast calculation. Usually the best practical results are achieved with using orthogonal symmetric or asymmetric wavelets. These properties only Haar's wavelet possess, but Gabor, Daubechies, Meyer's wavelets, biorthogonal and others are used also.
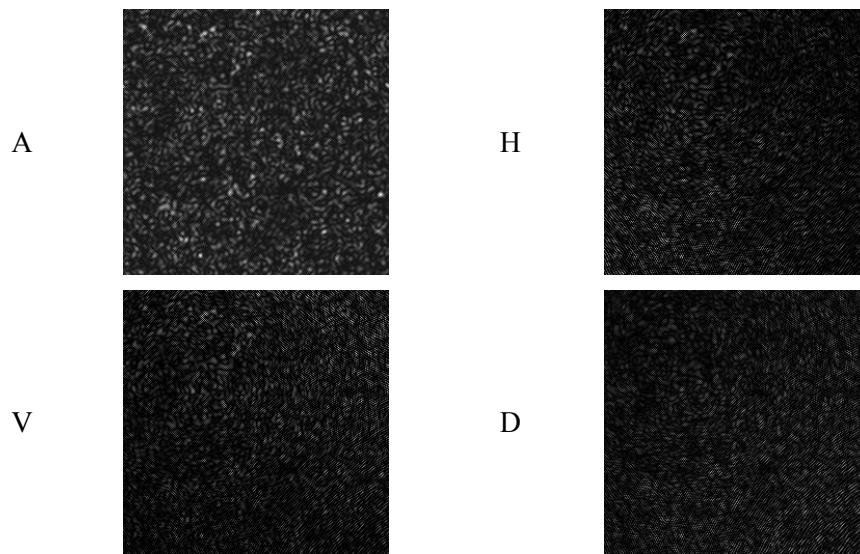
Figure 2. Wavelet transform of digital hologram: approximating (A), horizontal (H), vertical (V) and diagonal (D) coefficients of decomposition

3. Parameters used in numerical experiments on digital holograms compression

Seven methods of compression of holograms based on various wavelet transforms have been realized in program environment. They are:

- Haar,
- Daubechies,
- Symlet,
- Coiflet,
- Biorthogonal,
- Reverse biorthogonal,
- Meyer.

For numerical experiments parameters which can be used in case of the experimental recording of off-axis digital Fresnel holograms were selected:

- wavelength of the laser illumination is 633 nm,
- pixel size is 8 μm × 8 μm,
- size of the hologram is 1024 × 1024pixels,
- distance from object to the digital camera's photosensor (hologram) plane is 0,94 m.

Standard grayscale test images with size of 128×128 pixels was used as the object image.

As quantitative criterion of reconstructed images quality, the normalized standard deviation (NSTD) [28] between reconstructed and initial images was used:

$$NSTD = \sqrt{1 - \frac{\left(\sum\limits_{\xi,\eta=1}^{N,N} E[\xi,\eta]F[\xi,\eta]\right)^2}{\left(\sum\limits_{\xi,\eta=1}^{N,N} E^2[\xi,\eta]\right)\left(\sum\limits_{i,j=1}^{N,N} F^2[\xi,\eta]\right)}} \qquad (1)$$

where $E[\xi,\eta]$ and $F[\xi,\eta]$ are matrices with intensities values of the initial and the reconstructed images respectively,

$[\xi,\eta]$ are discrete coordinates,

$N×N$ is quantity of pixels of images.

NSTD value shows degree of visual resemblance to original image, including similarity in reproduction of halftones.

Diffraction efficiency (DE) of modeled digital holograms was calculated also. DE can be found as product of two values:

- DE_H – relative part of power of illumination that was passed through the hologram,
- DE_O – relative part of power of informative diffraction order under reconstruction.

DE was found as follows [14]:

$$DE = DE_H \cdot DE_O = \left(\frac{\langle H[u,v] \rangle}{max\{H[u,v]\}} \right)^2 \cdot \left(\frac{\sum_{\xi,\eta=1}^{N,N} F_O[\xi,\eta]}{\sum_{\xi,\eta=1}^{N,N} F[\xi,\eta]} \right) \tag{2}$$

where

- $H[u,v]$ is matrix with intensities values of the hologram pixels,
- $[u,v]$ are discrete coordinates in the hologram plane,
- $max\{*\}$ – maximum value of intensity of pixels of the hologram,
- $<*>$ – average value of the intensities of the object beam in hologram plane,
- $N×N$ is quantity of pixels of reconstructed image,
- $F_O[\xi,\eta]$ is matrix with intensities values of the reconstructed object image (informative diffraction order)only,
- $F[\xi,\eta]$ is matrix with intensities values of the full reconstructed image.

4. Comparison of quality of reconstructed image from compressed digital holograms

Quality of reconstructed images from compressed digital holograms by seven wavelet transform was estimated. Obtained dependences of the NSTD values on quantity of gradations of wavelet-coefficients are shown in Fig. 3. Digital holograms were compressed by 1-level wavelet transform.
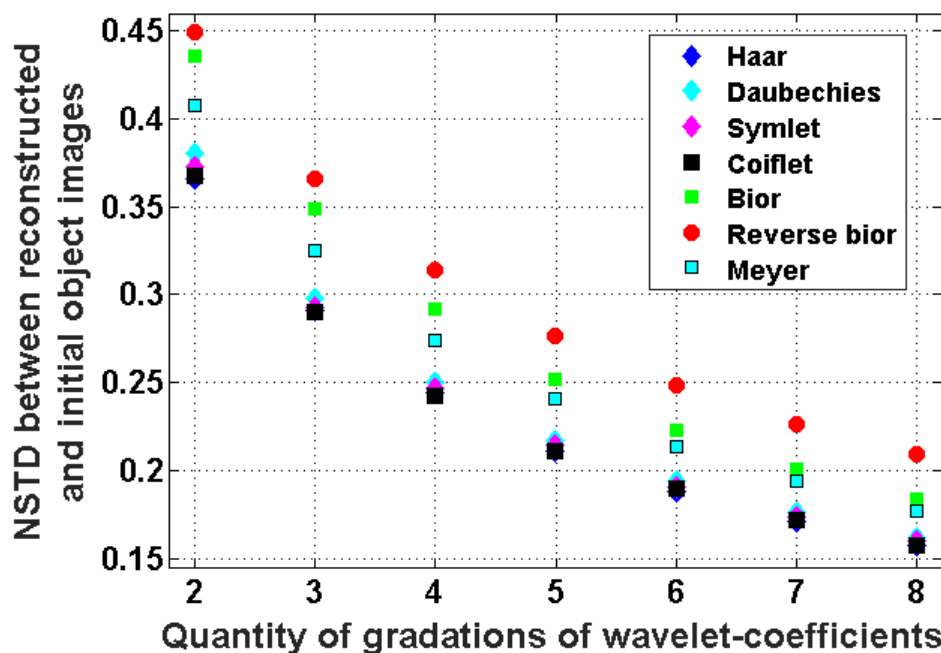

Figure 3. Obtained dependences of quality reconstructed from the compressed holograms images on quantity of gradations of wavelet-coefficients.

As can be seen, the best quality of reconstruction is achieved with using coiflet, symlet and Haar's wavelet transforms. The worst quality of restoration is obtained with the reverse biorthogonal wavelet and biorthogonal wavelet. Reconstruction of images from compressed with different wavelets holograms in case of 8 gradations of wavelet-coefficients are shown in Fig. 4.
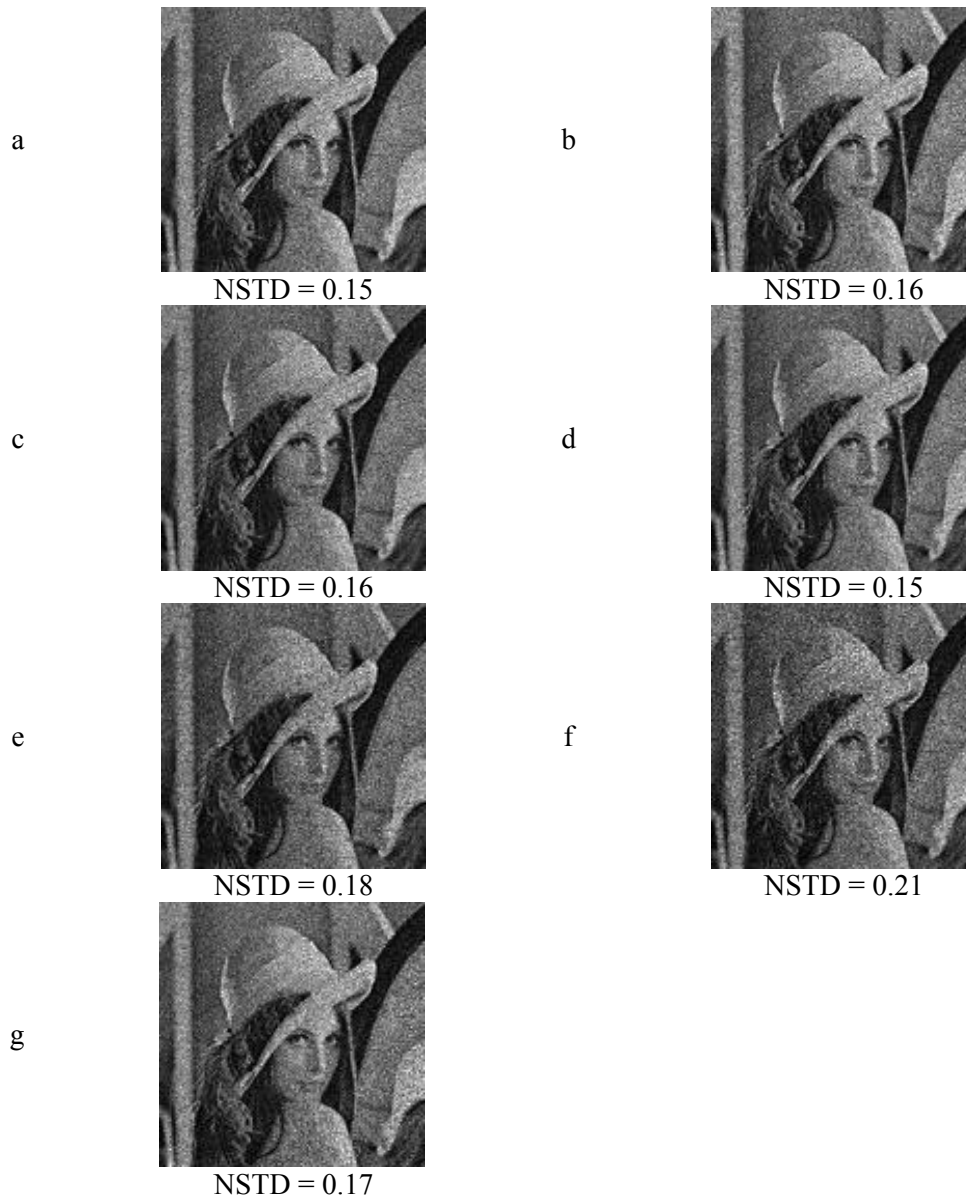

a
NSTD = 0.15

b
NSTD = 0.16

c
NSTD = 0.16

d
NSTD = 0.15

e
NSTD = 0.18

f
NSTD = 0.21

g
NSTD = 0.17

Figure 4. Reconstructed images of the halftone object for different wavelet transform: Haar (a), Daubechies (b), symlet (c), coiflet (d), biorthogonal (e), reverse biorthogonal (f), Meyer (g) in case of 8 gradations of wavelet-coefficients

5. Comparison of diffraction efficiency of compressed digital holograms

In addition to comparison reconstruction quality, diffraction efficiencies were estimated also. Obtained dependences of diffraction efficiency of the compressed holograms on quantity of gradation of wavelet-coefficients are shown in Fig. 5. Digital holograms were compressed by 1-level wavelet transform.
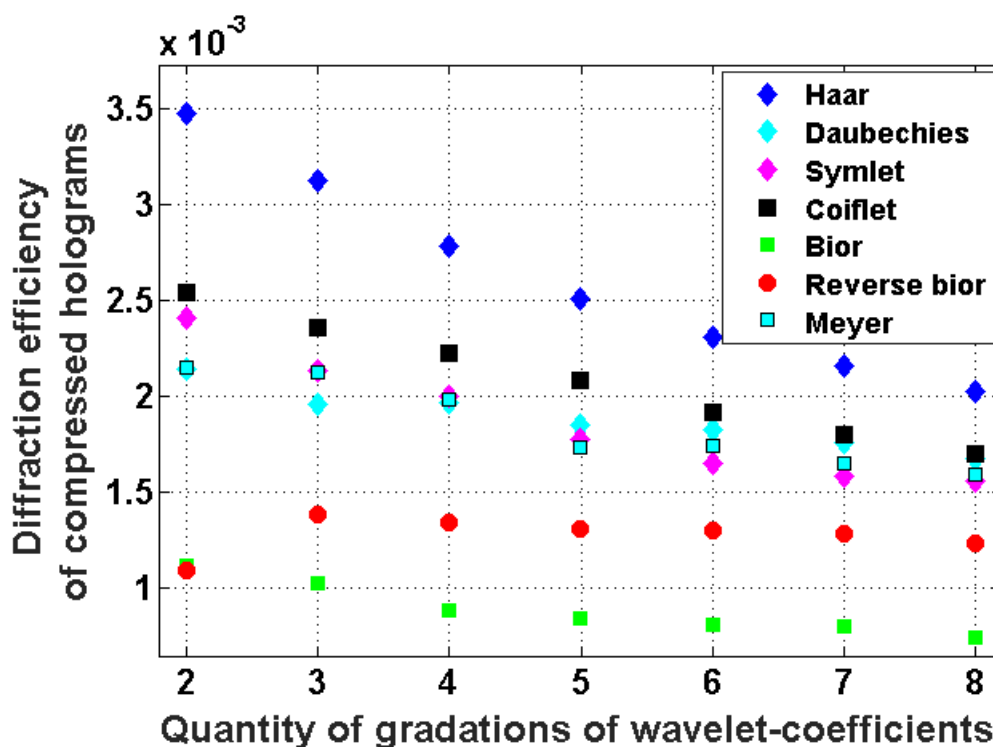
Figure 5. Obtained dependences of diffraction efficiency of compressed holograms on quantity of gradation of wavelet-coefficients.

The highest values of diffraction efficiency are achieved using Haar wavelet transform. The lowest values of diffraction efficiency are obtained when biorthogonol and reverse biorthogonol wavelet transforms wavelet are used.

To further compress digital holograms several techniques can be used. Possible method of such compression is use of multiple levels of wavelet transform. Also zerofilling on a threshold (thresholding) can be used. In this case all values of wavelet-coefficients less certain value of a threshold are nullified. Increase of a threshold will raise compression ratio, but, at the same time, increase quality losses. Reduction of the threshold allows to reduce quality losses of compression, but reduces its efficiency. Except thresholding of coefficients of wavelet-decomposition it's quantization is possible.

6. Conclusion

In this paper the most popular wavelet transforms were applied for digital holograms compression. Quality of the reconstructed images and diffraction efficiency of compressed holograms were obtained. Comparing these parameters, it is possible to determine the most optimal type of a wavelet transform for compression of digital holograms.

In case of the compression based on 1-level wavelet transform, the most optimal methods (according to the best quality of reconstruction and the highest diffraction efficiency) are Haar's wavelet transform and coiflet. However using other wavelet transforms with more levels of compression can provide other results than in case of 1-level compression.

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