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Usage of Artificial Neural Networks Method for Image Enhancement of Reconstructed Image in Digital Holography

Sayısal Holografide Geri Elde Edilen Görüntünün İyileştirilmesi İçin Yapay Sinir Ağları Metodunun Kullanılması

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Abstract

The aim of paper is to use an artificial neural network approach for enhancement of three dimensional image reconstructed in digital holography. An artificial neural network method based on Gerchberg-Saxton algorithm is implemented to reduce the noise and increase the brightness of this image. The results of proposed method have been presented by a relative error. In addition, these relative error figures are supported with error histogram obtained from MATLAB neural network fitting toolbox.

Keywords: Artificial neural network, Digital holography, Gerchberg-Saxton algorithm, Image enhancement

Öz

Bu makalenin amacı, yapay sinir ağları yaklaşımını sayısal holografide hologramdan geri elde edilen üç boyutlu görüntünün iyileştirilmesi için kullanmaktır. Gerchberg-Saxton algoritmasına dayalı yapay sinir ağları metodu, gürültünün azaltılması ve bu görüntünün parlaklığının arttırılması için uygulanmıştır. Önerilen metodun sonuçları, bağıl hata ile sunulmuştur. Ayrıca, bu bağıl hata şekilleri, MATLAB yapay sinir ağları araç kutusu ile elde edilen hata histogramları ile desteklenmiştir.

Anahtar Kelimeler: Yapay sinir ağları, Sayısal holografi, Gerchberg-Saxton algoritması, Görüntü iyileştirme

1. Introduction

Dust particles, sensor temperature and undesirable light levels make up the environmental effects for digital holographic setup (DHS). During image acquisition or transmission, these effects can affect the image sensor (Maity et al. 2015, Verma and Ali 2013). In addition, the low spatial resolution of image sensor creates a loss of the display quality in three dimensional (3D) reconstructed images (Zhang and Zhou 2014). Noise reduction process of the reconstructed image is also needed for image enhancement. To improve the image quality and increase the spatial resolution, many studies have so far been conducted in DHS. For instance, Dyomin et al. proposes a new method for holographic image enhancements of particles by levelling the intensity of image back ground (Dyomin et al. 2014). Moreover, to improve the quality of reconstructed images, the method of the frequency extrapolation is implemented to large object under the diffraction limit by Liu et al. (Liu et al. 2016).

Aside from the studies of image enhancement described above, researchers have focused on iterative algorithm in recent studies. Gerchberg-Saxton algorithm (GSA) is the most popular iterative algorithm, which is used for phase retrieval with the numerical iterative process (Gerchberg and Saxton 1972). Nakamura et al. have proposed a numerical technique to obtain an accurate complex amplitude by determining the phase sign iteratively (Nakamura at al. 2007). Latychevskaia and Fink suggest the usage of self-extrapolation of holograms for the resolution enhancement of reconstructed images in digital holography by carrying out an iterative reconstruction process (Latychevskaia and Fink 2013). Additionally, different filtering techniques based on soft computing approaches such as genetic algorithm (GA), artificial neural network (ANN), artificial bee colony (ABC) optimization, etc. have been performed by researches. Farnood Ahmadi et al. studied the image

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processing algorithm for high resolution satellite images with using ANN (Farnood Ahmadi et al. 2008). Torali and Kandarpa performed a de-noising technique using feed forward artificial neural network (FFANN) to remove the speckle noise (Saikia and Sarma 2014). Latifoglu introduced an ABC algorithm for speckle noise filtering (2D FIR filter) in an ultrasound image application (Latifoglu 2013). Moreover, the ANN is used for fast particle characterization in 2016 (Schenider et al. 2016).

In addition to all, ANN and GSA are used for image enhancement. Although GSA is a famous method, the image quality of reconstructed image obtained by using this method is unsatisfactory. It is proposed that a better image enhancement of reconstructed image obtained from GSA is achieved by training process with ANN. This proposed method is also named shortly as ANN method with GSA. The training process is performed by back propagation algorithm being a multilayer and supervised learning algorithm for feed-forward network in ANN (Duda and Hart 2000, Hect-Nielsen 1989, Hornik et al. 1989). The input and target output vectors, which are initially given with supervised learning, are trained by this network (Pinjare and Kumar 2012). In addition, Multi-layer perceptron (MLP) network is used to constitute the ANN architecture (Duda and Hart 2000). The reconstructed image, which will be used as ANN input layer parameter, is obtained from Fourier transform method(FT). The reconstructed image obtained by using GSA is used as ANN target output.

This paper is organized with four sections. In section II, the recording process of experimental hologram is described. In addition, GSA and ANN method are presented. The experimental results with detailed discussion are given in section III. Additionally, the relative errors are presented to show the image enhancement. The error histogram is given and mean relative error is calculated to support the result of relative error figures. Finally, section IV is conclusion part.

2. Materials and Method

2. 1. The Used Algorithm in Experiment

The ANN based on GSA is used to improve the image quality and increase the spatial resolution of 3D images in digital holography. In this section, the experimentally hologram recording is described. Moreover, the iterative methods of GSA and ANN are introduced.

2.1.1 The Experimentally Hologram Recording

The Lensless Fourier digital holography (LFDH) setup, which is used in the experimental part, is given in Figure 1 (Ustabaş Kaya and Saraç 2017).

He-Ne laser with the wavelength of 633 nm is selected as a light source. The laser light is divided into two arms via cube beam splitter (BS). The beam from the black arm (object arm) is reflected on the object surface by transmitting through the M1 and L1. The beam from the red arm (reference arm) is passed through the spatial filter and neutral density filter respectively and then reflected the M2. These beams coming from two arms are dropped on the CCD camera and create the interference pattern (hologram) on CCD camera in this system. The signal processing parts are performed on the computer after the cretaed hologram is transferred to the PC via an interface.

Fourier transform method (FT), which is a classic algorithm, is used to reconstruct the hologram. The twin image and zero diffraction order problems occur after reconstruction process. These problems are digitally eliminated by filtering.

The reconstructed 3D images obtained with twin image and zero diffraction order problems are given in Figure 2 for housefly image.

2.1.2 The Gerchberg-Saxton Algorithm

This algorithm is one of the main iterative methods that is

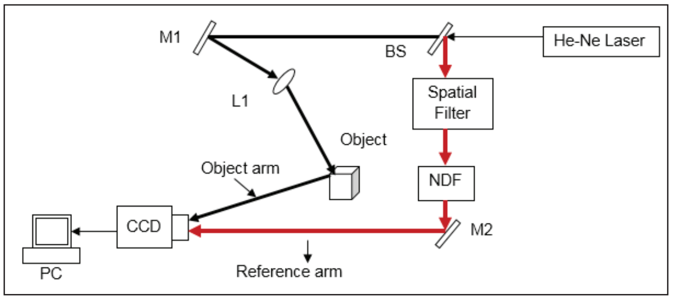

Figure 1. The recording setup of LFDH. (**BS:** Beam splitter, **NDF:** Neutral density filter, **M1:** Mirror 1, **M2:** Mirror 2, **L1:** Lens 1, **CCD:** charge-coupled device, **PC:** personal computer).

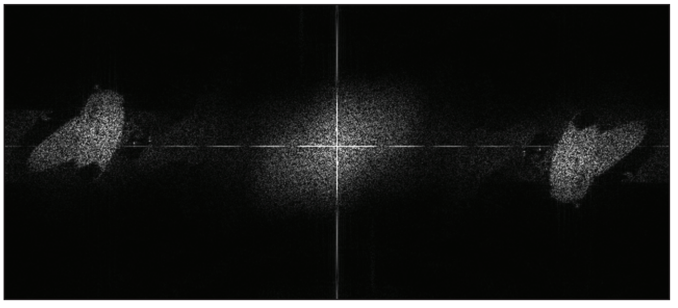

Figure 2. The reconstructed 3 dimensional image obtained with twin image and zero diffraction order problems.

used to retrieve the phase. This method which was added to literature in 1971 for the first time is especially used for non-periodic objects (Gerchberg and Saxton 1972, Shechtman et al. 2015, Avidor and Gur 2010). It is suggested to retrieve the phase information by taking a Fourier Transform (Takeda and Mutoh 1983) of object amplitude and to correct this phase information.

We can mathematically define the original Gerchberg-Saxton algorithm. By using the Fourier transform of the recorded hologram, random phase information can be found. This phase can be named as θ_{in} where A_{in} is given as the beginning amplitude of the hologram. The hologram obtained from the random phase and amplitude informations of beginning recorded hologram is calculated by using Equation 1.

$$A_1 = A_{in}(x)\exp(i\theta_{in}(x)) \tag{1}$$

Here A_{in} is assumed as 1. A_2 is obtained by taking Fourier transform of A_1. This transform is given in Equation 2.

$$A_2 = \mathcal{F}(A_1) \tag{2}$$

It is passed to the Fourier domain by using equation 2. The new phase is obtained from A_2 by using FT algorithm and it is called as θ_{out}. The output amplitude, which is given in Equation 3, is also defined as A_{out}. The value of A_{out} is calculated by taking the root mean square of the recorded hologram at the beginning.

$$A_3 = A_{out}(x)\exp(i\theta_{out}(A_2)) \tag{3}$$

Finally, by inverse FT of the Equation A_3, it is passed to the spatial domain and it is aimed to reach the beginning hologram amplitude. The obtained hologram is described as A_4 and it is given in Equation 4.

$$A_4 = \mathcal{F}^{-1}(A_3) \tag{4}$$

After this step, the phase information is gained again by using FT from the A_4. If this phase value is the same with the beginning phase value, the iteration is finished. If not, the iteration will continue till the first phase value is found.

The requisite iteration number in GSA is determined according to reconstructed images, which are accepted as the best results without noiseless. In this study, this iteration number has been found as 10.

The mathematical expressions of GSA, can be shown block diagram in Figure 3.

2.1.3 The Usage of Artificial Neural Network based on GSA

ANN method is used for training the 3D reconstructed image, which is obtained from GSA. Multi-layer perceptron (MLP) network is implemented to create the architecture of ANN. This network bases on error back propagation algorithm. A balance between the input and target output dataset is carried out by using MLP (Isa et al. 2010). The most popular architecture of MLP consists of three layers: input, hidden and output layers. Also all connections between these layers are connected with each other for this architecture. The Figure 4 gives the MLP network with one hidden layer that is used in our study.

The first layer as input layer consists of a set of neurons which are used as the input parameter to the network. The ANN based model is designed with MLP to reduce noise on holographic images. The reconstructed holographic image obtained from FT and eliminated from twin images becomes the input layer element. It is well known that neural network is to train the algorithm on a large dataset. The matrix array of reconstructed image is used as input dataset. The matrix array is given as N in Figure 4. The second layer as hidden layer consists of one or more layers. This layer bases

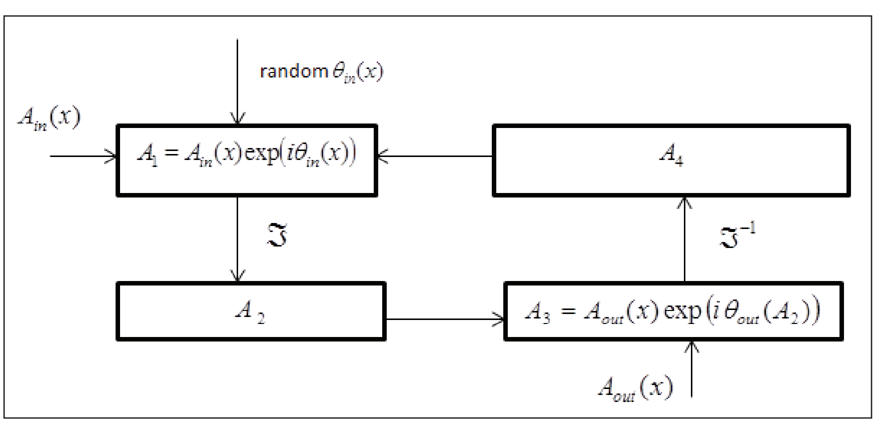

Figure 3. The block diagram of the Gerchberg-Saxton algorithm.

on the training process. Mean Squared Error (MSE) for the performance criteria are calculated after training process for different numbers of hidden layer neurons. Because, the changing MSE values affect the image enhancement of 3D reconstructed images. The number of hidden layer neurons is chosen as 12 according to calculated MSE values. The reason is that the image enhancement of the reconstructed images cannot change visibility after using of 12 neurons. In Table 1, the training MSE values of MLP according to different number of hidden layer neurons are given for star, dice and housefly images respectively. Because MSE values change depending on different images.

The last layer as output layer gives the output parameter of ANN. Firstly, the system is trained by using input and

Table 1. The training MSE values of MLP according to different number of hidden layer neurons for star, dice and housefly images respectively.

The Number of Hidden Layer Neurons	MSEs		
	MLP for star	MLP for dice	MLP for housefly
4	5.12006×10^{-4}	9.65636×10^{-4}	5.67182×10^{-4}
6	4.13796×10^{-4}	9.33678×10^{-4}	5.59844×10^{-4}
8	4.14498×10^{-4}	9.27439×10^{-4}	5.51273×10^{-4}
10	4.14496×10^{-4}	9.22492×10^{-4}	5.48111×10^{-4}
12	4.09697×10^{-4}	9.29457×10^{-4}	5.49875×10^{-4}
14	1.27063×10^{-3}	1.53361×10^{-3}	3.27532×10^{-3}
16	2.93290×10^{-3}	2.91114×10^{-3}	2.90856×10^{-3}
18	2.12113×10^{-3}	1.83378×10^{-3}	1.81978×10^{-3}

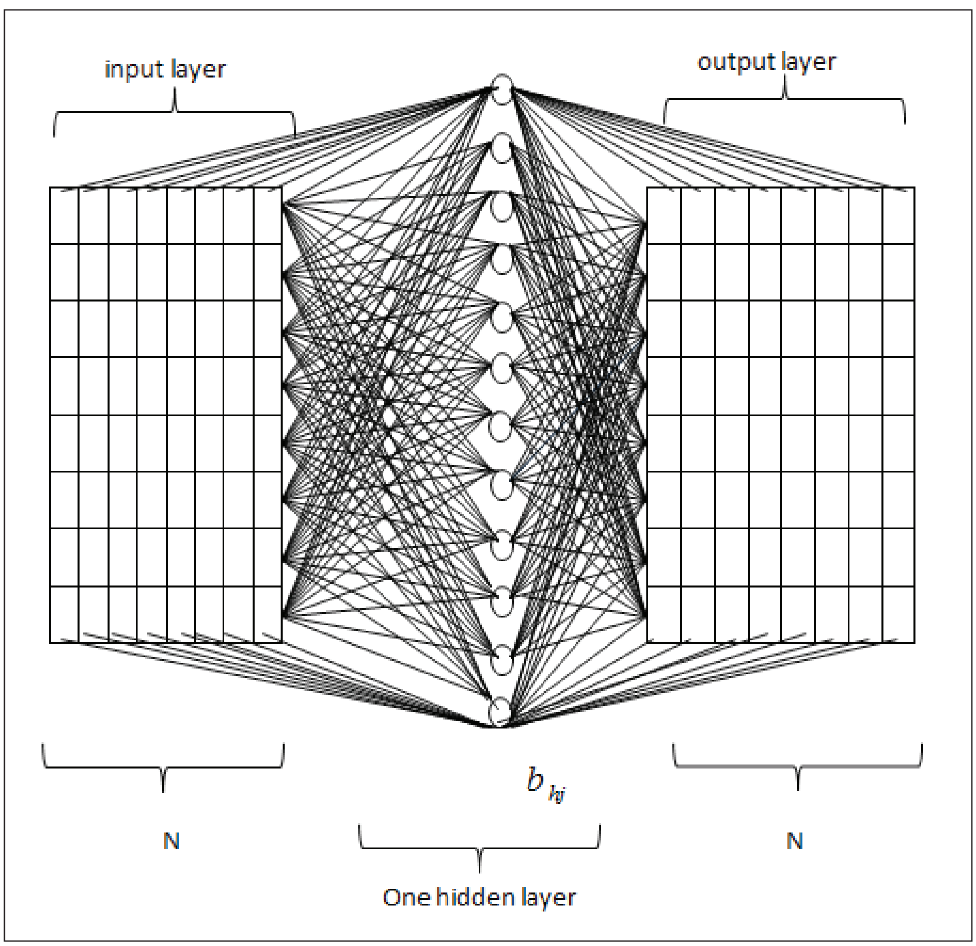

Figure 4. The model of multi-layer perceptron network with one hidden layer.

output data. The error value between the input and output data is back propagated to hidden neurons and the weights are updated. After certain iteration, the errors are already minimized. By using one hidden layer, the output of MLP is calculated by Equation 5.

$$y = f_0\left\{\sum_{k=1}^{m} f_h\left(\sum_{j=1}^{n} w_{hj}x_j + b_{hj}\right)w_{ok} + b_{ok}\right\} \tag{5}$$

Here, the input parameter is given as x_j and the output parameter is shown as y. f_0 and f_h are given as hidden layer activation function and output layer activation function respectively. The input-hidden layer weights, hidden layer biased, hidden-output layer weights and output layer biased are identified as w_{hj}, b_{hj}, w_{ok} and b_{ok} respectively.

The suitable transfer function, which is called as activation function, must be found for MLP. Therefore the weights are updated. For this process, PURELIN, is used as output layer activation function. The MATLAB Neural Network Fitting Toolbox (nftool) is implemented for the ANN application process of this study and the algorithm of TRAINLM is chosen.

3. Results and Discussion

In this section, the results of enhanced 3D image reconstructed from hologram in digital holography are presented. The enhancement is achieved for dice, star and housefly images respectively. These images are used as sample objects. In Figure 5, the images reconstructed from holograms of sample objects are shown. They are used as input layer data for ANN method and named as input images.

In addition, the images obtained by GSA after 10 iterations, are given in Figure 6 for sample objects. They are used as target image for ANN method.

To show the difference between input images and images obtained from GSA method, the relative errors are present-

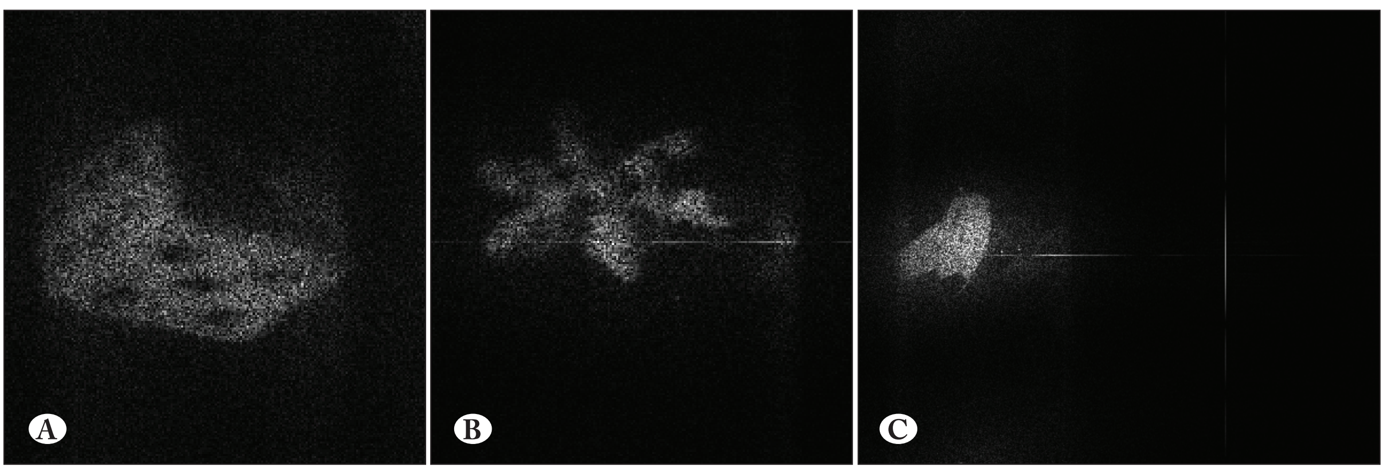

Figure 5. The image obtained by FT from Hologram **A)** of dice **B)** of star **C)** of housefly.

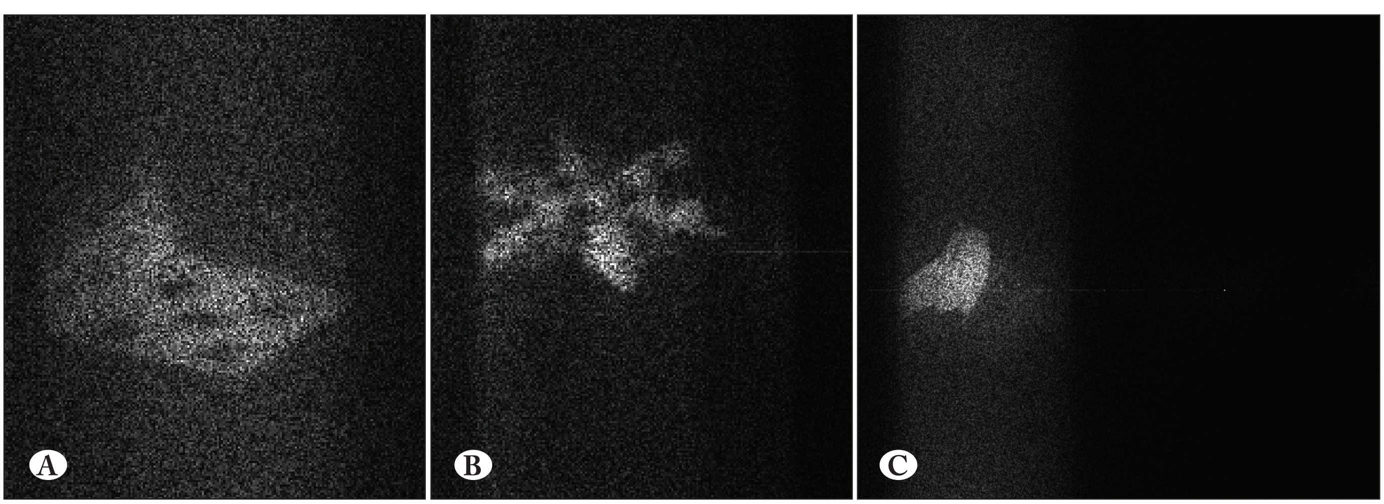

Figure 6. The image obtained by GSA **A)** for dice **B)** for star **C)** for housefly.

ed. The results are given in Figure 7a, Figure 7b and Figure 7c for dice, star and housefly images respectively.

As seen from Figure 7, the image enhancement obtained by GSA method cannot completely be achieved. Namely, the dice, star and housefly images cannot be distinguished from relative errors shown in Figure 7.

Therefore, another iterative approach such as ANN method is proposed for the first time for enhancement of 3D image reconstructed from hologram in digital holography. The needed training process for ANN is provided by using MATLAB NFTOOL and to train the network, 1000 epochs are adapted. The training process is checked out after every 5 epochs. In addition, 80% of the matrix is used for training process, 10% for test process and 10% for validation. The performance goal is met at 25 iterations for dice image, 105 iterations for star image and 10 iterations for housefly image. In Figure 8 the graphical performance analysis of

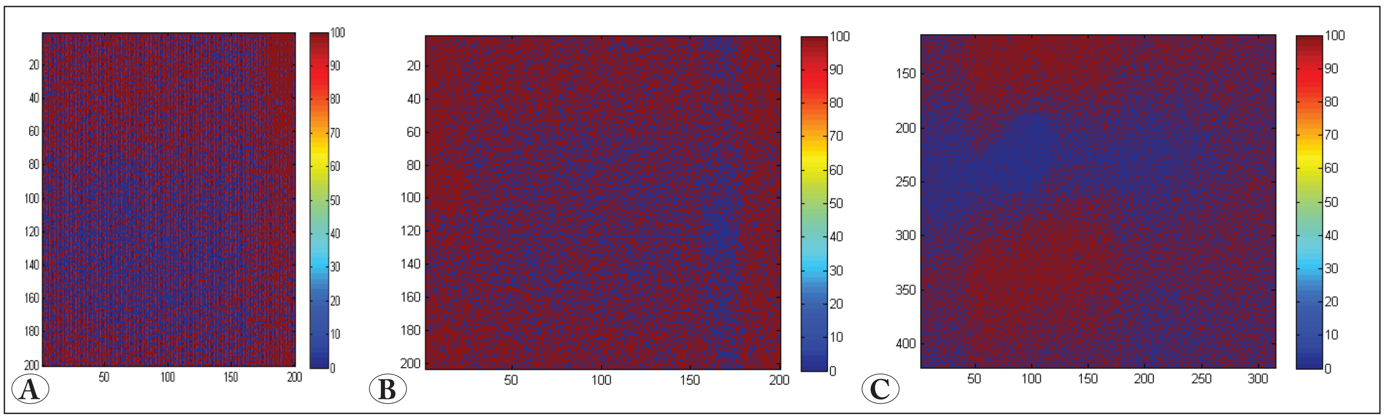

Figure 7. The relative errors **A)** between 5(a) and 6(a), **B)** between 5(b) and 6(b), **C)** between 5(c) and 6(c).

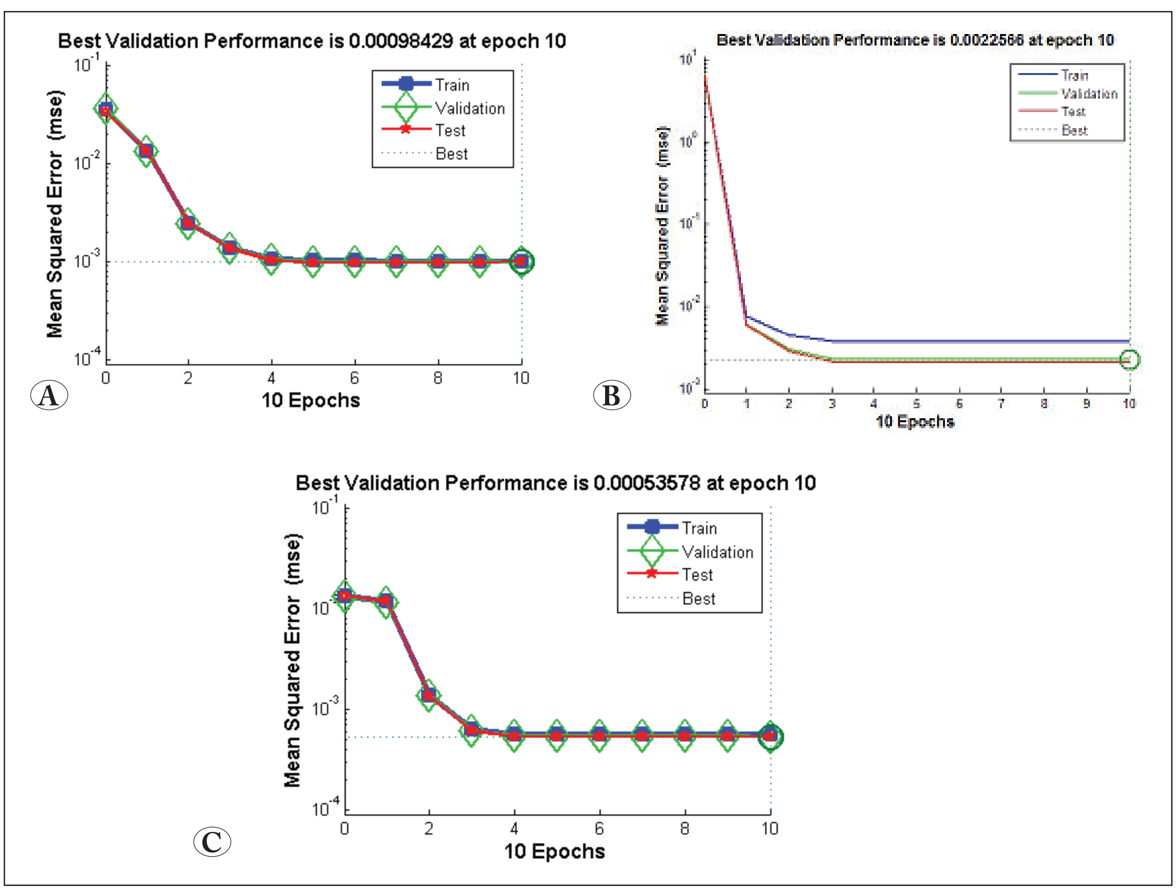

Figure 8. The performance analyses of number of epochs versus MSE **A)** for dice **B)** for star **C)** for housefly.

number of epochs versus MSEs are given for dice, star and housefly images respectively. It seems from Figure 8 that the best training performance is obtained at epoch 10.

To implement the training process of ANN method with GSA, input images given in Figure 5 are used as an input layer parameters. After training process, the results of ANN method with GSA are presented in Figure 9 for sample objects. The relative errors between the reconstructed images of input images and images obtained with ANN methods with GSA are shown in Figure 10a, Figure 10b and Figure 10c for dice, star and housefly respectively.

The images of dice, star and housefly are also used to show the accuracy of proposed method for sample objects. Therefore these images can be seen more clearly.

In addition to relative errors, the error histograms are obtained via MATLAB NFTOOL toolbox. These histograms are given in Figure 11.

As seen from Figure 11, the error histograms of images support the relative errors given in Figure 10a, Figure 10b and Figure 10c. These figures indicate the outliers. The blue bar represents the training data in this figure. As for that the green and red bars, they represent the validation and testing dataset. The matrix of reconstructed image having 480 x 640 pixels is used as the dataset.

In addition to error histograms, the mean relative errors of the images reconstructed from holograms are calculated numerically. The calculated results for dice, star and housefly images are given in Table 2.

Table 2. The mean relative errors of sample objects.

The Sample Objects	Mean relative erros
Dice	88%
Star	86%
Housefly	97%

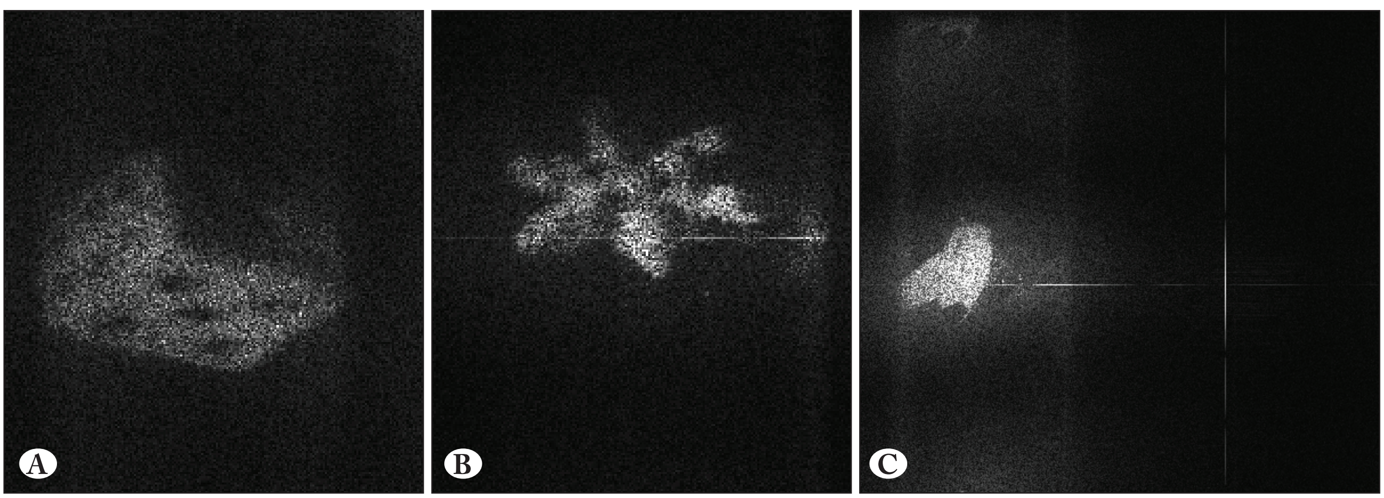

Figure 9. The images obtained by ANN method with GSA **A)** for dice **B)** for star **C)** for housefly.

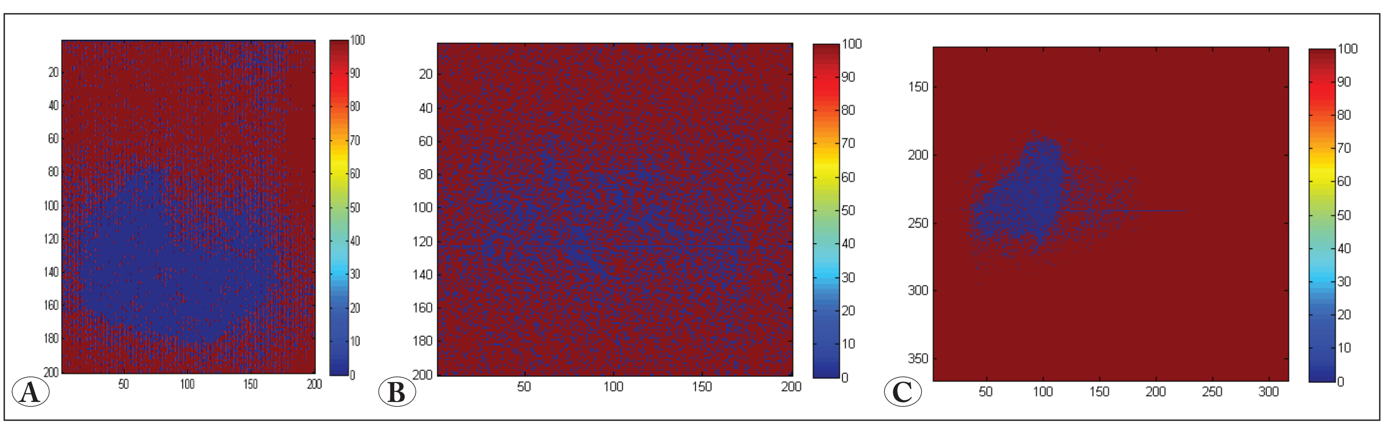

Figure 10. The relative errors of 3D images **A)** between Figure 5a and Figure 9a. **B)** between Figure 5b and Figure 9b. **C)** between Figure 5c and Figure 9c.

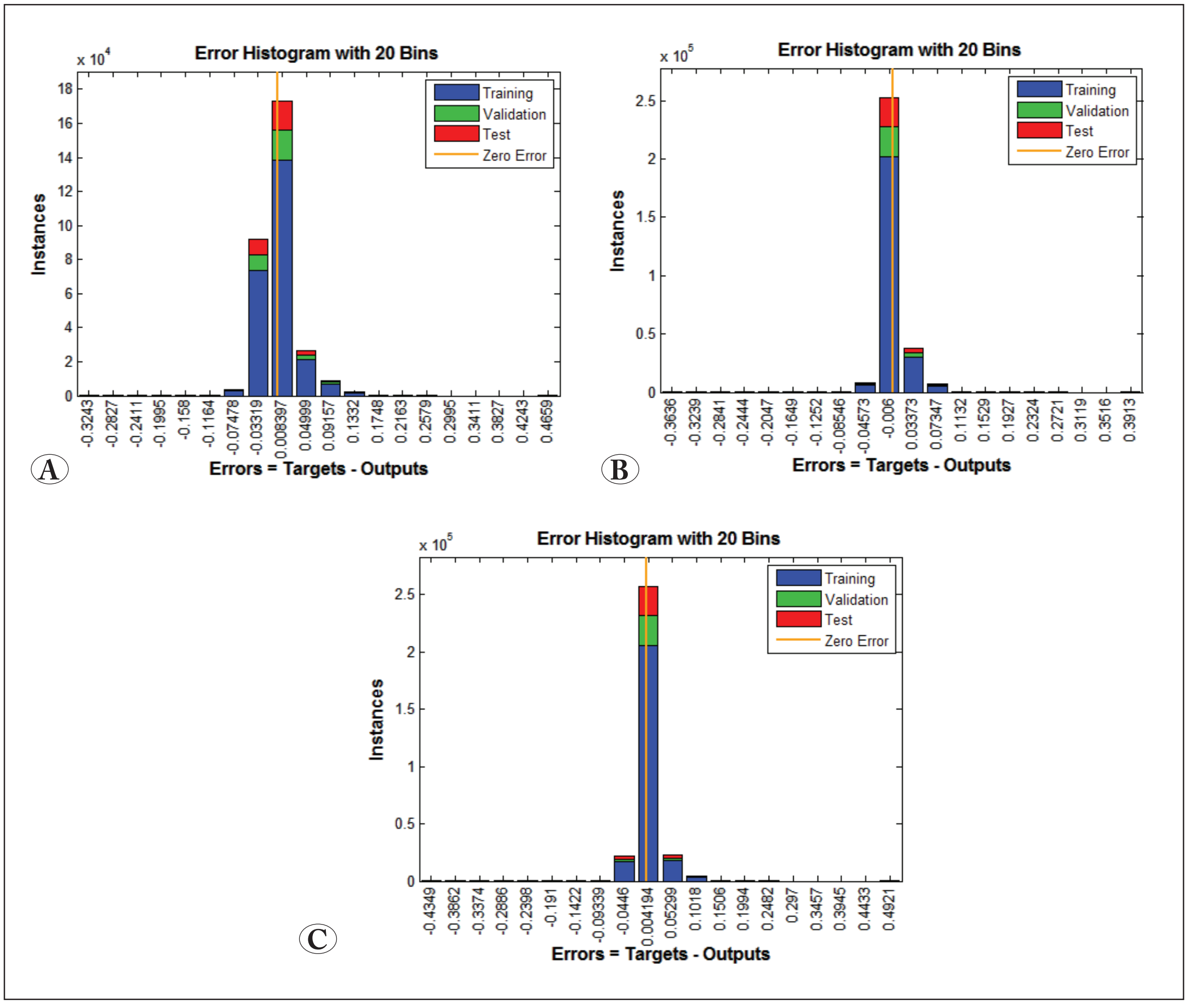

Figure 11. The error histograms obtained from ANN method with GSA **A)** for dice **B)** for star **C)** for housefly.

Here, the performance of ANN method with GSA is measured by calculating the mean relative errors. The input image is trained by using ANN to eliminate the noise of the images. If the input image is compared by output image obtained by using proposed method, the result of mean relative error can be expected over 85%. It seems in Table 2 that, the proposed method exhibit the high accuracy for images.

4. Conclusion

The usage of ANN method with GSA is used to improve image quality and to increase the brightness of 3D image reconstructed in digital holography. The training process of ANN is provided by MLP and here ANN is based upon GSA. The results obtained from ANN method with GSA are given with the relative errors. In addition, the error histograms for sample images support the results of relative errors. Finally, the performance of proposed method is given with high accuracy by calculating the mean relative errors.

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