**MARMARA UNIVERSITY**

**FACULTY OF ENGINEERING**



**DENOISING DIGITAL HOLOGRAPHY IMAGES USING WITH NEURAL NETWORK ARCHITECTURES**

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**GRADUATION PROJECT REPORT**

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**FACULTY OF ENGINEERING**

**DENOISING DIGITAL HOLOGRAPHY IMAGES WITH USING NEURAL NETWORK ARCHITECTURE**

**by**

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**OF**

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**AT**

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# ABSTRACT

Digital holography technology, which is widely used in many different fields today, is developing and improving itself day by day. We see that this technology, which is expected to be used in the future, is used effectively especially in the field of health. The limits of this technology, which provides easier and clearer imaging in many different fields such as Pathology, Hematology, and so on, are not limited to this. It is a fact that this technology, which is now frequently used in the industrial field, will appear in every aspect of our lives.

Digital holography technology can be developed in terms of both content and production. One of them is noise reduction. In this imaging method, where the environment and light factors are very important, even the smallest factor can create noise. In this project, it is aimed to find a solution with artificial neural networks technology to reduce the noises. The main goal of the project is to reduce the noise generated by training the algorithm to an acceptable amount using the data set we have. The artificial neural networks algorithm to be used in this project was determined as the CNN (Convolutional Neural Networks) algorithm. This algorithm is one of the leading algorithms that can be used in many different fields and projects. The purpose of choosing the CNN algorithm The CNN algorithm is one of the most suitable algorithms for recognizing and describing the image. The datasets we have will be used to train the algorithm, and if necessary, it is considered to expand the datasets we have through different sources. The algorithm trained with data sets will be integrated into the system and tested with different digital holographic images.

Smoother and clearer images are obtained with digital holograms with reduced noise. The use of this in many different fields, including medicine and industry, is among the priority targets. In addition, we think that the project will be an improvable system that will also contribute to undergraduate / graduate students.

# LIST OF SYMBOLS

**z:** Rayleigh distance.

: Wavelength.

k: wavenumber.

j: imaginary number.

# ABBREVIATIONS

**CNN:** Convolutional Neural ​Network

**ANN:** Artificial ​Neural ​Network

**GAN:** Generative ​Adversarial Network

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# INTRODUCTION

Digital holography technology is one of the widely used technologies today. It would not be wrong to say that it is used in many important areas. One of the areas where this technology is most widely used is biomedical imaging. The change created by digital holography technology in this field is an undeniable fact. It is a fact that this technology, which is used especially in cell imaging, is a new science called Digital Holography Microscopy. We can see that this technology, which is also used in imaging processes such as tomography with 3-dimensional imaging technique, grows by improving itself day by day. In addition, in the industrial field, we can see many different benefits of digital holography technology used in many different sectors. To give an example of one of them, it is also used to detect minor problems in aircraft. Digital holography technology is used to examine these problems, which may be too small to be seen with the naked eye, before they get bigger. However, when using holography technology, the quality of external factors and the materials used also affect the image created. Such reasons cause distortions and noises in the hologram image, and these noises can cause small or large problems in research.

In this project, using artificial neural networks architecture to eliminate these noises in an acceptable way and to obtain a cleaner hologram image. The algorithm to be used in artificial neural networks will be the CNN (Convolutional Neural Networks) algorithm. The reason for choosing this algorithm is that this algorithm is the optimum result in denoising research.

## Thesis Content

This project includes the following topics:

* Basic information about digital holography.
* General information of digital holography technology.
* General information of Neural Network architecture.
* Neural network layers.
* Basic information about digital holography.
* Similar research that done before and their results.

# RESEARCH OBJECTIVE

**DIGITAL HOLOGRAPHY**

A digital camera and computer processing are used in digital holography to capture and display 3D pictures. It is based on the holographic concept, which includes capturing the interference pattern between an object beam and a reference beam to produce a 2D image that also contains the item's 3D information. Digital holography employs a digital camera to capture the interference pattern, which is then processed by a computer to create a 3D image, in contrast to classical holography, which records the interference pattern on film or another photographic medium.

Digital holography's capacity to take pictures in real-time is one of its key benefits. This makes it applicable to industries like security, where it may be used to produce 3D photographs of things for inspection, and medical imaging, where it can be used to capture real-time photos of interior organs. In addition, industrial inspection can make use of digital holography to check for flaws on an object's surface.

High-resolution 3D images may be produced with digital holography, which is another benefit of the technology. The resolution of the film or photographic medium used to capture the interference pattern can be a drawback for traditional holography. The resolution of digital holography is solely constrained by the capability of the computer and the resolution of the digital camera. This makes it possible to record and display extremely detailed 3D images.

In conclusion, digital holography is a procedure that uses a digital camera and computer processing to capture and show 3D pictures. It can record real-time photos and produce high-resolution 3D images, making it helpful in a variety of industries like security, industrial inspection, and medical imaging.

**NEURAL NETWORK ARCHITECTURE**

A neural network architecture is a term used to describe the layout and composition of a neural network, a kind of machine learning model. Neural networks are made up of layers of interconnected nodes, or synthetic neurons, and are modeled after the composition and operation of the human brain. The synapses that connect these neurons allow for the signal transmission between them. The quantity of layers, the density of neurons inside each layer, and the nature of connections between the neurons all affect the architecture of a neural network.

The feedforward neural network, usually referred to as a multi-layer perceptron, is one of the most widely used neural network architectures (MLP). Information only flows in one direction, from input to output, in this architecture since each layer's neurons are completely coupled to those in the layer above them. This design is appropriate for jobs like speech and picture recognition, where the input data must pass through several levels of processing before the output can be produced.

Convolutional neural networks (CNN), another well-liked neural network architecture, are made to handle data with a grid-like layout, such as image and video. Convolutional, pooling, and fully linked layers are some of the layers that make up CNNs. The pooling layers are used to down-sample the data and reduce its dimensionality while the convolutional layers are in charge of extracting features from the input data. The final classification or regression tasks are carried out using the fully connected layers. CNNs are especially helpful for applications like semantic segmentation, object detection, and image classification.

In conclusion, neural network architecture describes the layout and composition of a neural network, a class of machine learning model that takes its cues from the organization and operation of the human brain. The feedforward neural network and convolutional neural network are the two most often used neural network architectures and are ideal for many applications like image and voice recognition and image classification, respectively.

In digital holographic images noise is a big problem. This problem can cause lots of another problems. In this project, it is aimed to reduce the noise on digital holography images with neural network architecture.

# RELATED LITERATURE

Denoising digital holography images with artificial neural network is not new. This method is often used when rule-based methods are not given accurate results. There are several articles and research about this topic.

A similar method was used in the article ‘Scattering Imaging as a Noise​ Removal​ in​ Digital Holography​ by​ Using​ Deep​ Learning’ [1]. This article published in 2022 and written by Meihua Liao, Yuliu Feng, Dajiang Lu, Xianye Li, Giancarlo Pedrini, Karsten Frenner, Wolfgang Osten, Xiang Peng and Wenqi He. In this article, noises in digital holography images are tried to be reduced by using artificial neuron networks and the methods used are explained in detail. They used off-axis holography images and reconstructed by using Fourier transform and they used MNIST dataset for obtaining hologram images. At the end their results are pretty accurate and satisfied. Their loss is low enough.

Another similar project is ‘Deep Learning-Based Wrapped Phase Denoising Method for Application in Digital Holographic Speckle​ Pattern​ Interferometry’ [2]. This article published in 2020 and written by Ketao Yan , Lin Chang , Michalis Andrianakis, Vivi Tornari and Yingjie Yu. In this article, noise generated in digital holographic speckle pattern interferometry is tried to be reduced by using CNN structure. The model and the mathematical expressions are explained in detailed. At the end their results are accurate and as we can see their CNN model works well.

Another comparable project is ‘Speckle noise reduction for digital holographic images using multi-scale convolutional neural networks’ [7]. This article published in 2018 and written by Wonseok Jeon, Wooyoung Jeong, Kyungchan Son and Hyunseok Yang. This article attempts to reduce speckle noise by using multi-scale convolutional layers. It was developed by adding 7x7 convolutional layers to the U-NET model in architecture. A batch normalizational layer was added after each convolutional layer and overfitting was tried to be avoided. DIV2K dataset is used as dataset. The hologram images were reconstructed with the Fresnel diffraction method. Looking at the experiments and results in this project, we can say that it has a good performance in noise reduction, both quantitatively and qualitatively.

Another article using a similar method is ‘Deep Learning Network for Speckle De-Noising in Severe Conditions’ [8]. This article published in 2022 and written by Marie Tahon, Silvie Montrésor and Pascal Picart. In this study, the noise on the phase map was tried to be reduced by using the DnCNN model. This model has 59 layers inside. Database is chosen HOLODEEP database which has included 25 images and their pixel size is 1024x1024. This database was created with a tiny speckle grain size and a medium signal-to-noise ratio for speckle de-noising in soft situations. Looking at the results and loss figures in this article, it can be said that the results are quite good. The project has achieved its purpose and can be a useful tool.

Also, there are lots of image denoising using by neural network architectures but just normal images not holography images. Some of in these articles or research GAN model has been used.

# DESIGN

## Realistic constraints and conditions

Digital holography technology affects lots of area. Head of this areas is medical imaging and biomedical imaging. With that technology, images can be examined in more detail and improvements can be made by making more specific comments. Especially in the Medical imaging with these technology imaging can be done much better, easily and in detail. With the noise reduction we can see our images clearer and more detailed. And if there is a small problem, it can be obtained easily.

One of the disadvantages of digital holography technology, which is predicted to be used in modern technology and in the future, is noise. The method tried to be reduced in this project can be used and improved in the future.

## Cost of the design

In this project there are only server costs. This price from Google Colab Pro.

|  |  |
| --- | --- |
| Service | Price |
| Google Colab Pro | 276 TL |

## Engineering Standards

**Software Standards**

There are 2 programming languages used in this project that are Python and MatLab.

Python language is the healthiest programming language to use in image processing and artificial intelligence. With its many libraries, it provides the opportunity and convenience to create layers in the CNN model, to process and read images. In this project, opencv and tensorflow libraries were used in general.

Matlab language, on the other hand, is multifunctional, which is mostly used in image analysis and display, and has better documentation than other languages. MatLab was used in this project to create holographic images and then reconstruct them with back-propagation.

For the python codes Google Colab Pro is used. Google colab is cloud based google service. It allows you to operate on high gpu and ram. In the pro version, it provides higher gpu and higher ram.

## Details of the design

In this project CNN model chosen because CNN is one of the most accurate NN method for the denoising images. This model has occurred 3 layers.

A particular kind of neural network layer called a convolutional layer is made to automatically and adaptively learn spatial hierarchies of information from input images. These filters—small matrices that are learnt during training—are used to do this. These filters execute a dot product between the filter weights and the overlapped image region as they go across the entire image.

The model is given non-linearity through the activation function, which enables it to learn more intricate representations of the input data. The rectified linear unit (ReLU) activation function was applied in this investigation. Positive values remain untouched while negative values are replaced with 0 via the ReLU activation function.

Batch normalization is used for resolving the internal covariate shift, faster training convergence, improve generalization, and give robustness to changes in network architecture. These advantages make batch normalization a crucial tool for successfully training deep neural networks. Also, batch normalization is used for to avoid overfitting.

Deconvolution layer’s main purpose is in a CNN (Convolutional Neural Network) is to perform upsampling or reconstruction of feature maps. The deconvolution layer contributes in increasing the spatial dimensions of the feature maps, opposition to conventional convolutional layers that downsample the input. By applying deconvolution operations, the layer enhances output quality and provides an improved representation of the input data by reconstructing the spatial features and enabling the network to capture finer patterns and structures.

For the loss function ‘Mean square error’ is used and the optimizer chosen as ‘Adam’ [6].

metin, ekran görüntüsü, renklilik, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Fig 4.1.1: Schematic of the CNN model

metin, menü, doküman, belge içeren bir resim

Açıklama otomatik olarak oluşturuldu

Fig 4.1.2: CNN Model output

# METHODS

**Digital Holography**

Digital holography is a method that records and reconstructs 3D images of things using the ideas of wave optics. Digital holography's mathematical underpinnings are based on the laws of wave interference and diffraction.

The first step in creating a digital hologram is to laser-illuminate the target item. A hologram is an interference pattern that results from the interference of the reference beam and the object's light at the recording plane. An imaging device, such as a digital camera, is then used to capture the hologram.

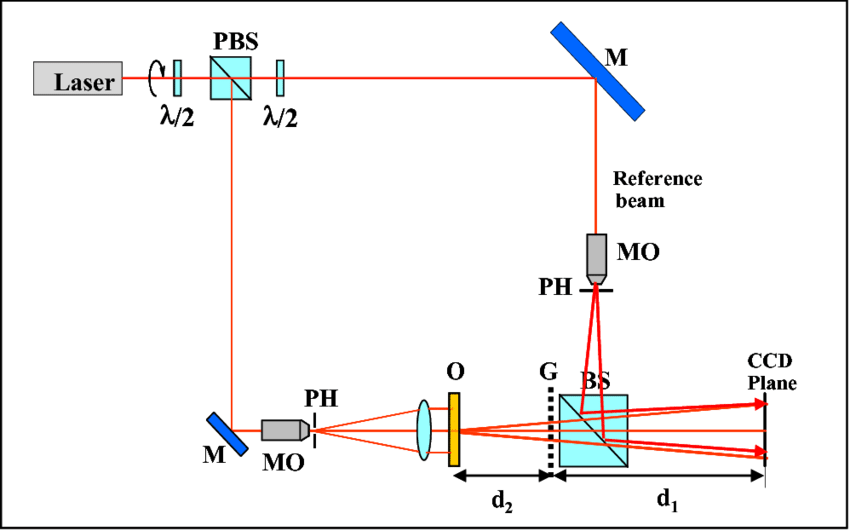


Fig 5.1.1: Digital holographic recording setup

Fresnel diffraction: Using the principles of Fresnel diffraction, the 3D object is then reconstructed from the acquired hologram. This procedure involves transforming the collected image into the spatial frequency domain using the Fourier transform.[3] Fresnel transform equation defines like:

|  |  |  |  |
| --- | --- | --- | --- |
| Name |  |  | Description |
| λ |  |  | Wavelength |
| v |  |  | Spatial frequency coordinate |
| µ |  |  | Spatial frequency coordinate |
| z |  |  | Rayleigh Distance |
| k |  |  | Wavenumber |

*(1)*

Table 5.1 Fresnel Transform Method Table

The inverse Fourier transform can then be used to recover the rebuilt image. In this step, the image is transformed back into the spatial domain, enabling the visualization of the 3D object. Given by is the inverse Fresnel transform formula.

*(2)*

Sometimes, during the capture procedure, the object wave's phase information is lost. An algorithm for phase retrieval must be applied to the recorded hologram in order to recreate the entire 3D object. The most popular approach is the transit of intensity equation (TIE) algorithm, which recovers phase information by utilizing the correlation between wave phase and intensity.[4]

In order to enhance the overall image quality, the 3D object can be further treated utilizing image processing techniques like denoising, segmentation, and augmentation.

**Neural Network**

A machine learning model called a neural network takes its cues from the structure and operation of the human brain. It is made up of layered networks of interconnected nodes, or neurons. Each neuron takes information from neurons in the layer before it to do calculations and generate outputs. The output is subsequently sent to the subsequent layer of neurons, where it stays until the output is completed.

Convolutional layers, batch normalization layers and deconvolution layers make up the three primary types of layers in the neural network architecture used in this study.

taslak, diyagram, metin, çizim içeren bir resim

Açıklama otomatik olarak oluşturuldu

Fig 5.1.2: Outline of CNN

The encoder network takes an input image and gradually reduces its spatial dimensions while increasing the number of filters through a series of convolutional layers with batch normalization and ReLU activation. The decoder network then takes the encoded representation and reconstructs the image by applying transposed convolutional layers, also known as deconvolution, which progressively increase the spatial dimensions while decreasing the number of filters. The final layer uses convolutional filters to output the reconstructed image with three color channels. This architecture allows the model to learn a compressed representation of the input image and then reconstruct it, effectively performing image compression and decompression.

**Dataset Progress and Training**

First part of this research is to be create a hologram with shapes images using with Fresnel transform method. Fresnel transform is used in propagation and back-propagation in this research [3].

In this project shapes dataset used. This dataset includes the geometrical shapes like circle, square, triangle and stars. There are 3200 200x200 images in this data set. Using with Fresnel transform equation, hologram images of the images of these shapes were obtained.

daire, vortex, kalıp, desen, düzen, sarmal içeren bir resim

Açıklama otomatik olarak oluşturuldu

fraktal çizim, sanat içeren bir resim

Açıklama otomatik olarak oluşturuldukalıp, desen, düzen, siyah beyaz, sanat, tasarım içeren bir resim

Açıklama otomatik olarak oluşturuldutasarım içeren bir resim

Açıklama otomatik olarak orta güvenilirlik düzeyiyle oluşturuldu

Fig.5.1.3: Amplitude images of hologram

çiseleme, yağış, yağmur, siyah beyaz içeren bir resim

Açıklama otomatik olarak oluşturulduAfter that, noise added in these hologram images with using standard deviation and mean. Mean arranged as 0 and standard deviation arranged as 0.2.

yağış, siyah beyaz, kabarcık, yağmur içeren bir resim

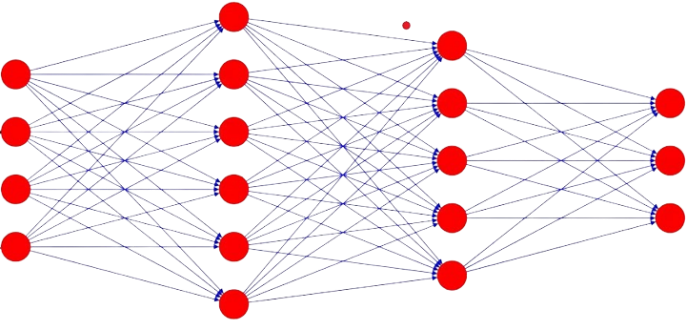
Açıklama otomatik olarak oluşturulduyağış, monokrom fotoğraf, monokrom, tek renkli, siyah beyaz içeren bir resim

Açıklama otomatik olarak oluşturuldudaire, su, sıvı, kabarcık içeren bir resim

Açıklama otomatik olarak oluşturuldu

Fig.5.1.4: Hologram images after adding synthetic noise

After that, noisy hologram images back-propogated using with Fresnel transform equation. 4-PSH technique used for reconstruct the image. Reconstructed images used to train the CNN model. The input given these noisy reconstructed images and the output is given to images in from shapes dataset. Learning rate arranged as 0.01, batch size arranged 64 and epoch number is 20.



yıldız, yaratıcılık içeren bir resim

Açıklama otomatik olarak oluşturulduyıldız, gri, siyah beyaz, yer içeren bir resim

Açıklama otomatik olarak oluşturuldu

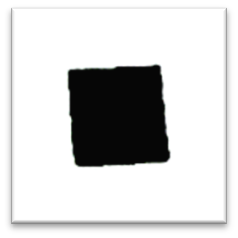


# RESULTS AND DISCUSSION

daire içeren bir resim

Açıklama otomatik olarak oluşturuldudaire, gri, siyah, siyah beyaz içeren bir resim

Açıklama otomatik olarak oluşturuldu

1. taslak içeren bir resim

   Açıklama otomatik olarak oluşturuldugri, dikdörtgen, ekran görüntüsü, kalıp, desen, düzen içeren bir resim

   Açıklama otomatik olarak oluşturuldu (b) (c)

(d) (e) (f)

yıldız, yaratıcılık içeren bir resim

Açıklama otomatik olarak oluşturulduyıldız, yaratıcılık, siluet içeren bir resim

Açıklama otomatik olarak oluşturulduyıldız, yer, siyah beyaz, deniz yıldızı içeren bir resim

Açıklama otomatik olarak oluşturuldu

(g) (h) (ı)

piramit, üçgen, koni içeren bir resim

Açıklama otomatik olarak oluşturulduüçgen, piramit içeren bir resim

Açıklama otomatik olarak oluşturuldusiyah beyaz, gri, üçgen, yer içeren bir resim

Açıklama otomatik olarak oluşturuldu

1. (j) (k)

Fig 6.1: Input noisy images (a, d, g, i), outputs (b, e, h, j), ground truth images (c, f, ı, k).

In this project, it is aimed to reduce the noise of hologram images with neural network architecture. We utilized a dataset of noisy reconstructed hologram images and noise-free reconstructed holography images. We trained a deep learning model to learn underlying patterns and structures in the data.

According to our results, the noise in reconstructed holography images was successfully decreased by the CNN-based denoising technique. Compared to the original noisy photographs, the denoised images showed more clarity, sharper edges, and better features.

# CONCLUSION

In conclusion, our project was successful in creating a CNN-based denoising method for holography images. The outcomes show that the suggested technique successfully lowers the noise levels in holography images, enhancing visual quality and realism.

The successful deployment of this CNN-based denoising approach offers up opportunities for numerous holographic applications. The denoised images may help holographic reconstructions be more accurate, make measurements easier to make, and generally increase the caliber of holographic imaging systems.

The successful implementation of this CNN-based denoising approach offers up opportunities for numerous holographic applications. The denoised images may help holographic reconstructions be more accurate, make measurements easier to make, and generally increase the quality of holographic imaging systems.

Overall, this project demonstrates the effectiveness of using a CNN for denoising holography images, highlighting the potential of deep learning techniques in the field of holography and image processing.

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# APPENDICES

## Appendix A

**Python code for CNN model**

model = Sequential()

# encoder network

model.add(Conv2D(filters = 128, kernel\_size = (2,2), activation = 'relu', padding = 'same', input\_shape = (128,128,3)))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 128, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 256, kernel\_size = (2,2),strides = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 256, kernel\_size = (3,3), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 512, kernel\_size = (2,2),strides = (2,2), activation = 'relu', padding = 'same'))

# decoder network

model.add(Conv2D(filters = 512, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.Conv2DTranspose(filters = 512, kernel\_size = (2,2), strides = (2,2),activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 256, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 256, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 128, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.Conv2DTranspose(filters = 128, kernel\_size = (2,2),strides = (2,2), activation = 'relu', padding = 'same'))

model.add(Conv2D(filters = 64, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

model.add(tf.keras.layers.BatchNormalization())

model.add(Conv2D(filters = 3, kernel\_size = (2,2), activation = 'relu', padding = 'same'))

# to get the summary of the model

model.summary()

## Appendix B

**Matlab code for creating holography images**

clear all

close all

clc

I = imread("17.png";

I=double(I;

M=200;

deltax=0.001;

w=633\*10^-8;

z=25;

delta=pi/2;

r=1:M;

c=1:M;

[C, R]=meshgrid(c, r);

A0=fftshift(ifft2(fftshift(I)));

deltaf=1/M/deltax;

p=exp(-2i\*pi\*z.\*((1/w)^2-((R-M/2-1).\*deltaf).^2-((C-M/2-1).\*deltaf).^2).^0.5);

Az=A0.\*p;

EO=fftshift(fft2(fftshift(Az)));

AV=(min(min(abs(EO)))+max(max(abs(EO))));

I0=(EO+AV).\*conj(EO+AV);

I1=(EO+AV\*exp(-1j\*delta)).\*conj(EO+AV\*exp(-1j\*delta));

I2=(EO+AV\*exp(-2j\*delta)).\*conj(EO+AV\*exp(-2j\*delta));

I3=(EO+AV\*exp(-3j\*delta)).\*conj(EO+AV\*exp(-3j\*delta));

MAX=max(max([I0, I1, I2, I3]));

first1 = I0/MAX;

first = imnoise(first1,'salt & pepper',0.02);

second = I1/MAX;

second = imnoise(second,'salt & pepper',0.02);

third = I2/MAX;

third = imnoise(third,'salt & pepper',0.02);

fourth = I3/MAX;

fourth = imnoise(fourth,'salt & pepper',0.02);