Image Denoising using Deep Learning: Convolutional Neural Network

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***Abstract*—It has become an important task to remove noise from the image and restore a high-quality image in order to process image further for the purpose like object segmentation, detection, tracking etc. This paper presents denoising of image using the convolutional neural network (CNN) model in deep learning. This analysis is done by adding 1% to 10% Gaussian white noise to the image and then applying CNN model to denoise it. Further, qualitative and quantitative analysis of the denoised image is performed. Under qualitative analysis comes the quality of image where edge factor, texture, uniform region and non-uniform region, smoothness, structure of objects is considered. The quantitative analysis is done using the three metrics which are PSNR (peak signal to noise ratio), SSIM (structural similarity index measurement), and MSE (mean square error) in which the CNN based method's results are compared with the traditional or standard methods of image denoising. The results from the analysis and experiment show that the CNN model can efficiently remove a lot of Gaussian noise and restore the image details and data than any other traditional/standard image filtering techniques.**

Keywords—Image denoising; convolutional neural network; Deep Learning; MATLAB; Gaussian white noise

I. INTRODUCTION

Digital image is playing an exceptionally huge role in many aspects of our daily life like they are utilized in satellite TV, intelligent traffic monitoring, signature approval, recognition of handwriting on checks, and also in other fields of science and technology like geographical information system and astronomy. Because of the impact of the transmission channels and other factors on the images are unavoidably being corrupted by noise during the process of acquisition, compression, and transmission resulting in the deformation and loss of image data. Image denoising is a classical technique which aims to eliminate the noise from the original image as much as possible and restoring image details. It is extremely difficult to differentiate between noise, edge, and texture during the process of image denoising because these are high frequency components and there could be loss of some details in the denoised image. For removing noise from the image without going through unnecessary smoothing of the important information, denoising technique must be spatially adaptive. Noise can be additive or multiplicative, depending on the type of noise present in the image an appropriate denoising algorithm is selected for removing the noise.[1]-[3]

During the process of image acquisition, often the image becomes degraded due to numerous reasons. The main purpose of image denoising is to estimate the original image from the noise contaminated version of the image by removing or suppressing the noise.[4]

Image denoising is one of the major hurdles in the field of image processing and computer vision. Often in practical situations it is not possible to avoid noise which may be produced by different intrinsic conditions like sensors and extrinsic conditions from disrupting an image. Therefore, it is very important to use image denoising and restoring techniques. [4]

Some basic methods of image denoising are Chroma and luminance noise separation, Linear smoothing filters, Anisotropic diffusion, Nonlinear filters, Wavelet transform filters, Block-matching algorithms, Random field machine learning algorithm, Deep learning, etc. These filters are used to suppress the noise effectively, preserve edges and provide a visually natural appearance.

Image denoising has impacted almost all technical fields and plays a significant role in many fields such as medical imaging (Gamma ray imaging, PET scan, X-Ray Imaging, Medical CT, UV imaging), astronomical imaging (removing noise from images captured by satellite), transmission and encoding, microscopic imaging, forensic science, image restoration, visual tracking, image registration, image segmentation, image classification and other areas where it is crucial to obtain the contents of original image for strong performance.[4]

In this paper, we have analysed the new feature of Deep Learning Toolbox introduced in MATLAB version R2019a by denoising an image using CNN. The benefit of using a CNN model is that it is optimizing continuously and hence improving the weights of convolutional kernel during training of network whereas traditional image denoising methods have fixed parameters and cannot be adjusted during filtering. We are using quantitative analysis parameters such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM) Index to check and compare the denoised image with the original image. Furthermore, we are comparing our results with other works in this field to find the best filter/algorithm for image denoising.

Section I Introduces about image denoising, its importance and application. Section II Provides the literature survey of image denoising. Section III Provides the flowchart and algorithm of image denoising using CNN. Section IV Shows the experimental analysis of image denoising using CNN. Section V Concludes the paper and gives the future scope of this topic.

II. LITERATURE SURVEY

A. Deep Learning

Rina Dechter in the year 1986 introduced the concept of deep learning in machine learning.[5] In 1965, the first paper on deep feed-forward multilayer perceptron was published. In 1980,for handwriting recognition zip codes on mail back propagation algorithm was applied to a deep neural network. By the year of 1991, such system were also used in recognizing 2D handwritten digit. In 1992, cresceptron method was applied for the recognition of 3D object in cluttered scene [30]. The concept of deep learning has been explored for several years. In 1998 Larry Heck with his team successfully used deep learning for speech processing. Furthermore, Hochreiter and Schimidhuber in the year 1997 used Long Short Term Memory (LSTM) which is a deep learning algorithm, for efficient speech recognition. In 2015, there was dramatic performance jump of about 49% in speech recognition system of Google due to the use of connectionist temporal classification (CTC) trained LSTM. [6]-[10]

Deep learning started to impact the industry from early 2000s when CNN was already being used for handwritten digit image recognition in most of the banks in US [29]. In 2009, Nvidia GPUs were used to speed up the deep learning system by 100 times so the use of deep learning increased as the training and running time reduced from weeks to days. In 2010 industrial application of deep learning was used in large scale speech recognition because researchers were able to expand the concept of deep learning from TIMIT to bulk vocabulary speech recognition.[11]-[12]

Deep learning was first used in medical field in 2012 as George E. Dahl predicted the biomolecular target of one drug using multi-task deep neural network. On November 2012, Ciresan build a system which analysed large medical images for detection of cancer. In 2014, Hochreiter detected noxious and toxic effects of chemicals in nutrients and domestic products by using the deep learning model [27].

Nowadays, Deep Learning has a wide range of application ranging from computer vision to Automatic Speech Recognition (ASR). On March 2019, Yoshua Bengio, Yann LeCun and Geoffery Hinton were awarded for their work in deep learning which has made deep learning a critical and necessary component of computing. [13]

B. Convolution neural network

In this paper we will be using the CNN model for denoising the image. The idea of CNN model came from vision processing in living organism. In the year of 1950s and 1960s, Hubel and Wiesel published their work which shows animal like monkey and cat contains neurons that exclusively respond to small regions of visual fields in their visual cortexes. Hubel and Wiesel in their 1968 paper found two basic forms of visual cell in the brain i.e. simple cells and complex cells and proposed a cascading model on them.[14]-[15]

The origin of CNN architecture was from ‘neocognitron’, a term introduced in 1980 by Kunihiko Fukushima.[16] Using Neocognitron two basic form of layers in CNN were introduced i.e. convolutional layer and downsampling layer. Often, max-pooling technique introduced by J. Weng is used in modern CNN. Over the decades there were many supervised and unsupervised learning algorithms were used to train the weights of neocognitron[17]

Nowadays, the CNN architecture is generally trained through backpropagation. In 1987, Alex Waibel introduced the time delay neural network (TDNN), it was the first convolution network which achieved shift invariance by utilizing weight sharing along temporal dimensions. [18]

Image recognition using CNN architecture was first done in the year 1989 by Yann LeCunin in which images of hand-written digits were recognized using backpropagation. LeNet-5 developed by LeCun in 1998, is a 7-level convolutional neural network that is used to categorize hand written digits. LeNet-5 was used by many banks to recognize numbers on cheques and documents. [19]

W. Zhang in 1988 created Shift Invariant neural network which was first used for image character recognition but later in 1991 it was enhanced for medical image processing and majorly used for automatic breast cancer detection.[20]

Even though the concept of CNN was first introduced in 1980s ,their breakthrough was in the 2000s. In 2004 it was proven by K. Jung and K. S. Oh that Graphic Processing Units (GPUs) can implement neural networks 20 times faster than on CPU [28]. Implementation of CNN using GPU were first done by K. Chellapilla in the year 2006 [21].

III. IMAGE DENOISING USING CNN

A. Step by step procedure

Step 1: Loading the original image in the MATLAB system by using imread() function.

Step 2: Add gaussian white noise to the original image with zero mean and variance ranging from 1% to 10%.

Step 3: Compare the difference between the original image and the noisy image with montage visualization method which places both the images next to each other for better comparison

Step 4: Estimate denoised image from noisy image using a denoising deep neural network specified by net.

Step 4.1: net loads the pretrained denoising convolutional neural network, ‘DnCNN’

Step 4.2: Build-in deep feed-forward CNN, called DnCNN is mainly designed to remove noise from images. By default, DnCNN has 20 convolutional layers with stride equal to 1 and padding equal to 1 with activation function ReLu and a batch normalization with 64 channels after each convolutional layer.

Step 4.3: There is a Final Regression Layer which uses mean square error to gives the regression output

Step 5: Display the final denoised.

B. Flowchart

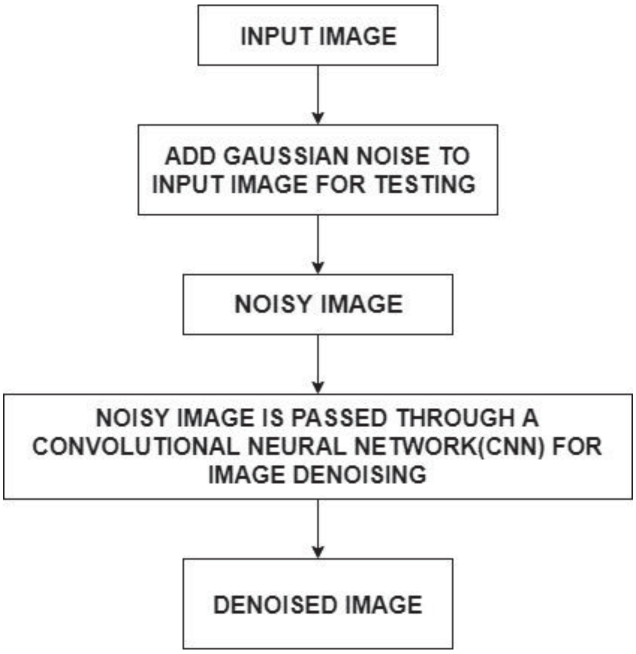


Fig. 1. Flowchart

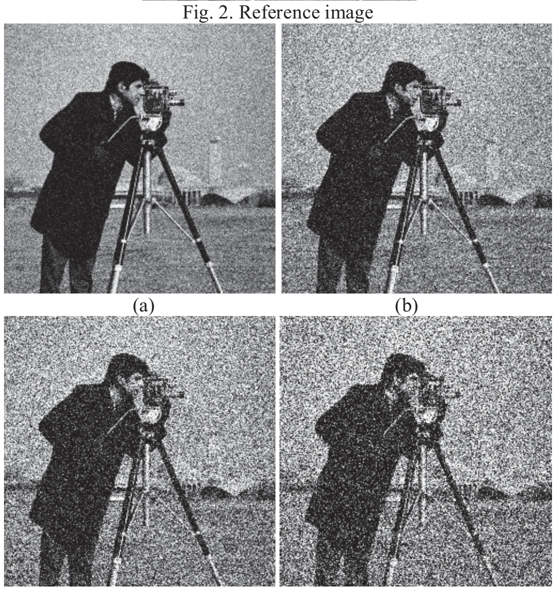
IV. FINDING AND DISCUSSION

The experimental testing of the discussed method is performed on various dataset images of Matlab software. But here in the paper, the results are presented on the "cameraman" image shown in the Fig. 2. The CNN based denoising method is tested at various noise variances (σ) i.e. σ = 1, 3, 6, and 10 as shown in the Fig. 3. The implementation is done using Matlab software, version: R2019a. The system configuration is of processor: Intel(R) Core(TM) i3-7020U CPU @ 2.30 GHz, RAM: 4.00 GB (3.84 usable), and 64-bit operating system, x64-based processor [22] – [23].

The denoising results of the discussed method are shown in Fig. 4. at above mentioned noise variances. The comparative analysis of denoising results are done by assessing the visual quality of image such as edge and texture preservation, smoothness in uniform regions, artifacts generation etc. The results are also assessed using certain metrics like Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM) Index. These parameters for image quality assessment are discussed in [22].

There are three basic approaches for image denoising i.e. spatial filtering, transform domain filtering and wavelet thresholding [24]. The results of CNN based denoising method is compared with some of the standard methods of previous discussed domains like Wiener filtering, Bilateral filtering, Principal Component Analysis (PCA), Wavelet based transform method, and Total Variation based regularization [25], [26].

Fig. 2. Reference image

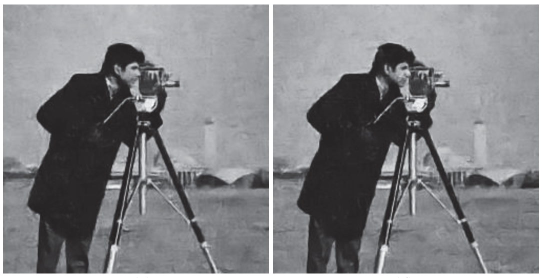


(a) (b) (c) (d)

Fig. 3. Noisy images at multiple noise variance (a) σ = 1% (b) σ = 3% (c) σ = 6% (d) σ = 10%

On analysing the Fig. 4, it is observed that denoising results are better at low level of σ, above it the results are not good as many of the objects are distorted as per Fig 4 (d). The denoising results can be more analysed by zooming the results.

(a) (b)



(c) (d)

Fig. 4. Denoised images at multiple noise variance (a) σ = 1% (b) σ = 3% (c) σ = 6% (d) σ = 10%

Fig 5, 6, 7, and 8 comparatively plots the histogram of all denoising results including reference image. This helps to analyse the results comparatively at different noise variances. If the curves of denoised image and reference image are closed to each other or they are overlapped, then that represents effective denoising results. In Fig 5-8, it can be well observed that the denoising results are better at low noise variances as both the curves are overlapped/ very near. While at high noise variances, the denoising results are also satisfactory as both the curves are not very far from each other.

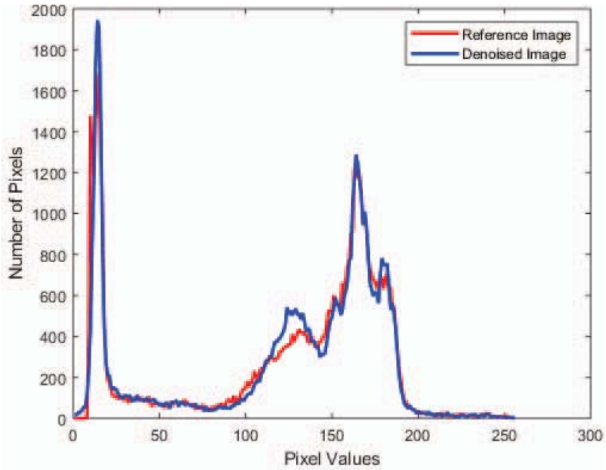


Fig. 5. Histogram plot of Fig 4 (a) (σ = 1%)

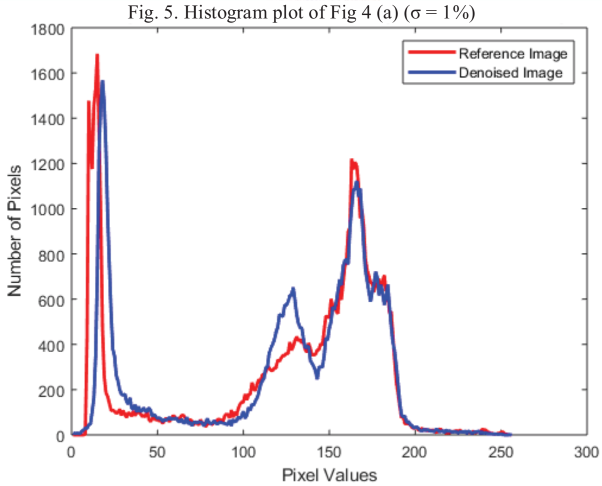


Fig. 6. Histogram plot of Fig 4 (b) (σ = 3%)

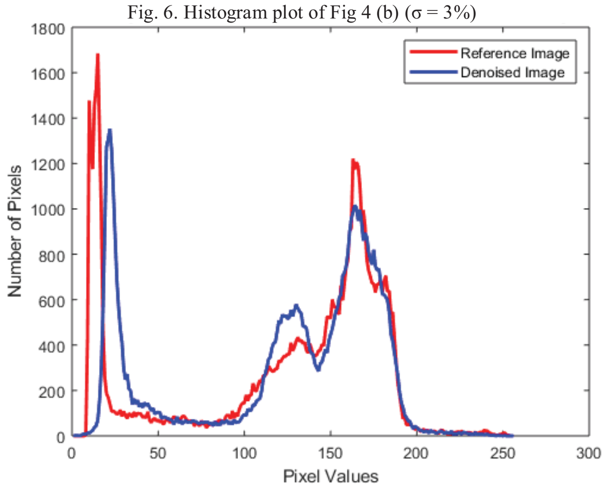


Fig. 7. Histogram plot of Fig 4 (c) (σ = 6%)

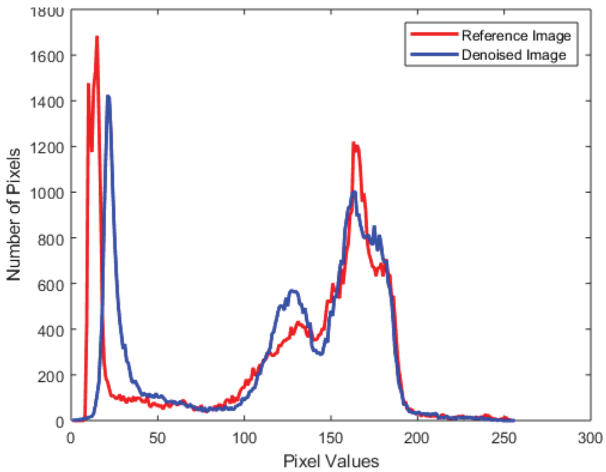


Fig. 8. Histogram plot of Fig 4 (d) (σ = 10%)

The qualitative analysis of all method's denoised images is performed in Fig 9. This kind of analysis is done by observing the visual quality of the denoised images. There are certain factors which are kept in mind while performing this analysis. Those parameters are edge and texture preservation, smoothness in uniform regions, artifacts generation, etc. The denoising results are calculated in Fig 9 is performed at σ = 7%. On observing the denoised results through naked eyes using visual quality attributes, it is found that smoothness in the uniform regions is lost in Fig 9 (a)–(d), while TV and CNN based denoising shows better smoothness in the uniform regions. Out of these two, CNN method shows better smoothness as there is no blurriness in the homogeneous part of the image. In terms of edge preservation, CNN based denoising method shows the best edge and fine detail preservation scheme as here in this method's result the corner of the object are well preserved while in the other method's results the edge and corners are not well preserved.

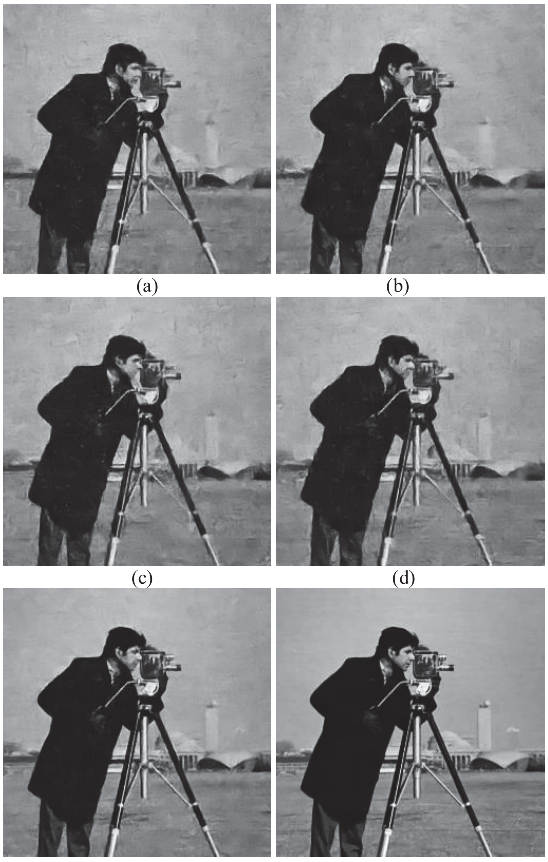


Fig. 9. Denoised Images (a) Wiener filtering (b) Bilateral filtering (c) PCA (d) Wavelet based transform method (e) Total Variation based regularization (f) CNN based denoising

Fig 10 comparatively analyses all the denoising results by plotting the histogram with respect to reference image. The reference image is depicted using pink colour. All other methods are represented using other different colors. The curves which are nearer to the pink color curve, those method shows better results due to high similarity with reference image. CNN based method (yellow colour curve) shows the highest similarity in comparison to other method.

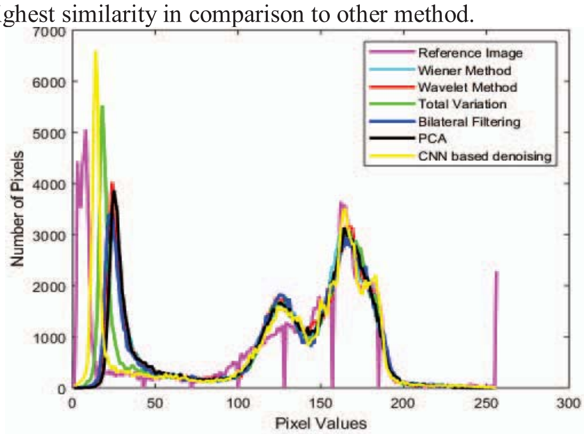


Fig. 10. Comparative analysis of all denoising results by plotting the histogram with respect to reference image

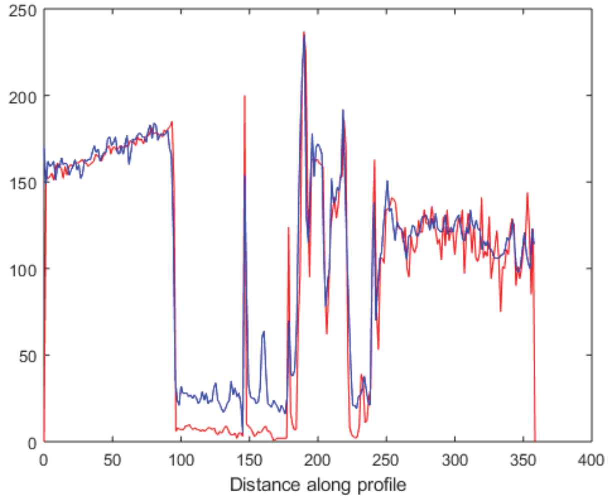
The quantitative analysis is performed using metrics like MSE, PSNR and SSIM in Table I. MSE helps to assess the similarity rate between reference image and denoised image. PSNR assess the overall performance of the denoising method. SSIM measures the similarity between denoised image against reference image. It depends upon three terms, luminance, contrast and structural term. Table I shows the overall best performance of CNN based denoising method. The parameter values of CNN method are better than all other compared method that shows overall best performance.

TABLE I. QUANTITATIVE ANALYSIS

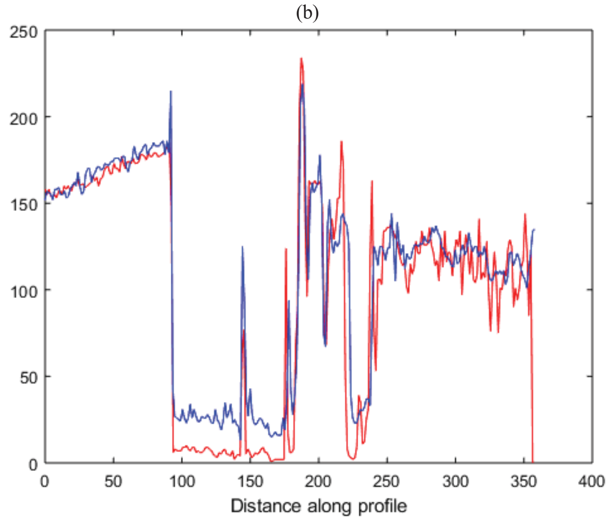
Image Denoising Methods	**Image quality assessment Parameters**		
	MSE	***PSNR***	***SSIM***
Wiener filtering	84.9830	25.0098	0.7872
Bilateral filtering	83.6294	25.9021	0.7982
PCA	80.9892	26.7834	0.8345
Wavelet based transform method	81.8765	26.1243	0.8181
Total Variation based regularization	81.3920	27.9898	0.9087
CNN based denoising	**78.4622**	**28.7126**	**0.9106**

Fig 11 shows the intensity profile of a line on Fig 11 (a), In each plot from (b)-(g), the noise free intensity profile is plotted in red and denoised profile is plotted in blue. This is a random test to assess the performance of denoising method. A random line is selected based on that part of image that has highest frequency change (heterogeneous region). Similarly the line is taken in Fig 11 (a). Based on this line, intensity profile is generated for reference image and all method's denoised image. If both the intensity profile overlaps then that method shows best results. Here in Fig 11, it is observed that CNN based denoising method shows best results due to highest overlapping.

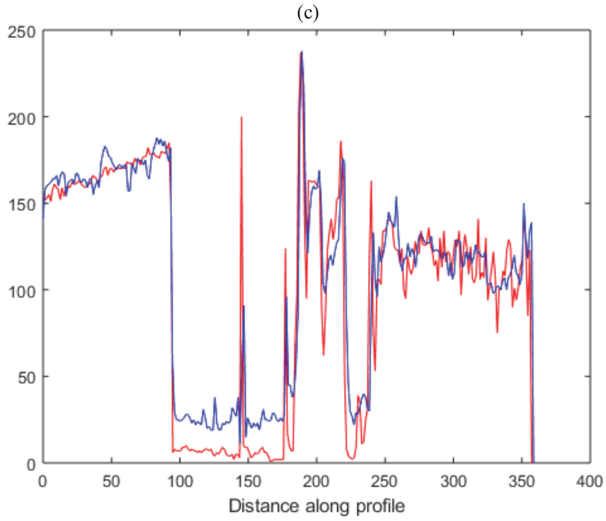
(a)



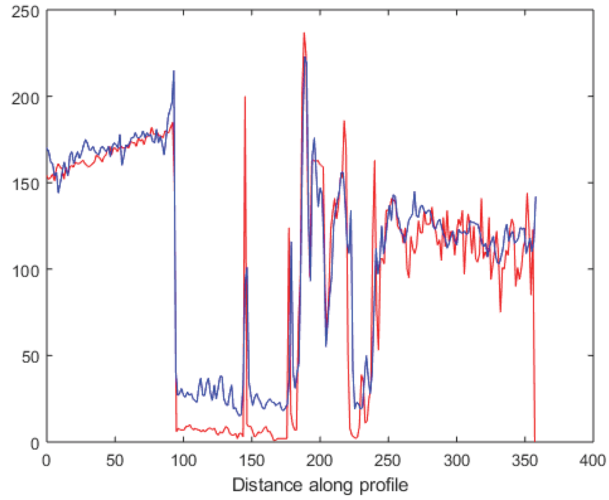
(b)



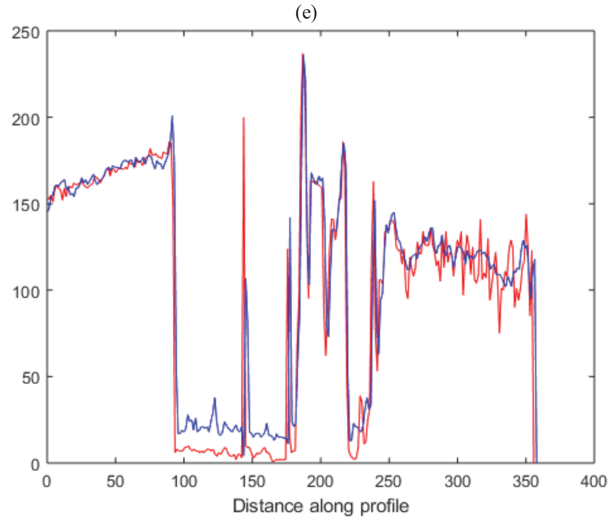
(c)



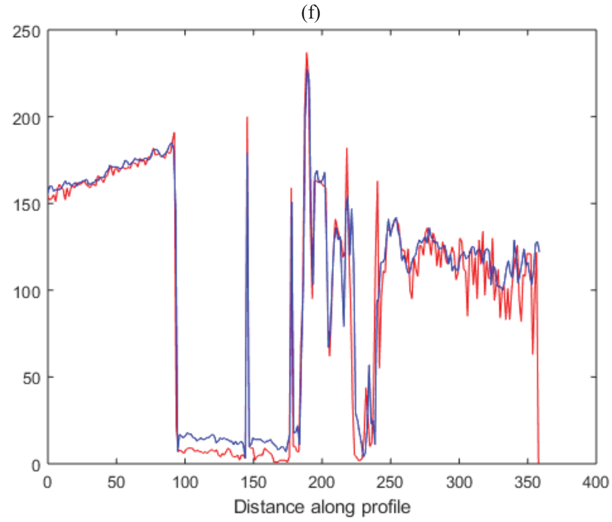
(d)



(e)



(f)



(g)

Fig. 11. Intensity profile of a line on (a), In each plot from (b)-(g), the noise free intensity profile is plotted in red and denoised profile is plotted in blue.

V. CONCLUSION

The paper studies about the CNN based image denoising and it also critically analyses its results and compare them with Wiener filtering, Bilateral filtering, PCA, Wavelet based transform method, and TV based regularization. In the paper, brief history of CNN based denoising method is discussed. The results are analysed at different noise variances and their denoised results are also seen on those noise variances. The qualitative and quantitative analysis is performed using visual quality of the image and using parameters like MSE, PSNR and SSIM respectively. Further the denoising results are analysed using histogram plotting and intensity profile method. On analysing all these methods, it is observed that CNN based denoising method shows best performance than all the other compared method.

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