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Edge Enhancement from Low-Light Image by Convolutional Neural Network and Sigmoid Function

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Abstract : Due to camera resolution or any lighting condition, captured image are generally over-exposed or under-exposed conditions. So, there is need of some enhancement techniques that improvise these artifacts from recorded pictures or images. So, the objective of image enhancement and adjustment techniques is to improve the quality and characteristics of an image. In general terms, the enhancement of image distorts the original numerical values of an image. Therefore, it is required to design such enhancement technique that do not compromise with the quality of the image. The optimization of the image extracts the characteristics of the image instead of restoring the degraded image. The improvement of the image involves the degraded image processing and the improvement of its visual aspect. A lot of research has been done to improve the image. Many research works have been done in this field. One among them is deep learning. Most of the existing contrast enhancement methods, adjust the tone curve to correct the contrast of an input image but doesn't work efficiently due to limited amount of information contained in a single image. In this research, the CNN with edge adjustment is proposed. By applying CNN with Edge adjustment technique, the input low contrast images are capable to adapt according to high quality enhancement. The result analysis shows that the developed technique significantly advantages over existing methods.

Keywords: Digital Image Processing, Image Enhancement, CNN, Edge adjustment, PSNR, SSIM.

I. Introduction

In the last decade, we saw a surge in multimedia content generated across the world. With the arrival of digital equipment like cameras, camcorders, etc., it became feasible for a large section of the world's population to generate such content. These devices have become increasingly popular, especially to improve their performance, their gradual loss of prices and their integration into mobile phones [1]-[5]. In fact, with the increasing mobility of these devices via mobile phones, combined with advances in low-cost storage, it was possible to capture multimedia content in the form of images and videos in an instant. The quality of an image are affected due to several conditions such as by poor illumination, atmospheric condition, wrong lens aperture setting of the camera, noise, etc [6][7]. So, such degraded/low exposure images are needed to be enhanced by increasing the brightness as well as its contrast and this can be possible by the method of image enhancement.

In digital image processing field one of the preprocessing technique is image enhancement which generates improved quality of the image out of the distorted or low enhanced image which shows its efficiency for applications in many areas and human interactions The image enhancement techniques are divided into two types, one is spatial techniques and other is frequency domain image enhancement [8]-[12]. In spatial domain image enhancement methodology, the pixels of an image enhance themselves directly in order to improve the image quality. Whereas in frequency domain image enhancement techniques, frequency transformation is performed on the pixel intensity values for their enhancement. As it is known that due to external atmospheric conditions such as fog or haze and many settings of camera or quality effects the image quality. So, there is requirement of such enhancement technique [13]-[15].

So, the degraded quality of image is enhanced by enhancing brightness as well as its contrast level. This can be done by many techniques or methodologies. Many researchers are contributing their efforts in this field as it has wide applications. The most common approach is to denoise the image by enhancing the pixel intensity as well as luminosity of an image.

Some research work are only intended to enhance image contrast and some are intended for denoising. But in real time application there is need for such adaptable algorithm that can enhance both according to the requirements [16]-[20].

II. Related Work

Bhattacharya et al. [21] used singular value decomposition (SVD) for enhancing the contrast of the image. This algorithm is also implemented over partially distorted images locally as well as globally. The performance of the enhancement is experimentally proved better performance over existing algorithms.

Dong-liang et al. [22] proposed image enhancement technique by designing generalized fuzzy algorithm that shows the enhancement over traditional fuzzy logic algorithm. This improved fuzzy logic approach gives enhanced result for contrast enhancement, segmentation and object recognition and enhances the result.

Xianghong et al. [23] designed image enhancement algorithm for colored medical images. According to the algorithm, first of all the two features are extracted i.e. color space and wavelet transform. Input image is sub-divided and wavelet analysis is performed. The RGB color space is converted into HSV color space and further calculations are performed and adjust the intensity of the input image and further converted back to RGB color space.

Verma et al. [24] proposed image enhancement using genetic algorithm because the fitness of the intensity of the spatial edge of the image. According to the algorithm, input image is sub-divided into sub blocks. According to the fitness value of the sub-blocks is selected with higher fitness value. PCA is applied for mutation of the genetic algorithm and outperforms better result.

Khan et al. [25] used DDFB diffusion filter and Hong filter for image enhancement of the fingerprint images in order to magnify the minutiae of the fingerprint images. The orientation of the fingerprint are calculated using multi-scale DDFB. The experimental result shows that this proposed algorithm is more reliable and efficient as compared to all other algorithms.

Shanmugavadivu et al. [26] designed an image contrast enhancement technique by applying histogram contrast enhancement technique using histogram equalization. According to this proposed technique, the histogram obtained from image is first of all divided into two parts based on Otsu threshold. Further particle swarm optimization is applied on each part respectively. Each part is separately optimized and finally joined together and enhance the brightness of the image.

Gorai et al. [27] proposed an image enhancement technique using particle swarm optimization (PSO) because this algorithm optimizes the objective function and its parameters. The local and global information are optimized to retrieve best options. The intensity of an image are optimized by applying this algorithm. Intensity transformation function are obtained as an result from this algorithm. Edge information and entropy are used as an objective function to be maximized. And finally, scaling is used to enhance the image quality. The algorithm gives better performance as compared to other techniques such as histogram equalization, filtering, etc.

Benala et al.[28] proposed an algorithm for magnification and enhancement of an image and termed this algorithm as ABC optimization algorithm. The result of this optimization is better as compared to genetic algorithm because the chance of dropping the local parameter optimization is less as in ABC algorithm. This algorithm improves the local maxima search ability such that global maxima will also be enhanced.

Hanumantharaju et al. [29]designed a technique by applying particle swarm optimization for enhancement of an image. Edge information and entropy of an image is used for enhancement of an image. Particle swarm optimization is thus used to optimize the parameters of the techniques such as multiscale retinex, Gaussian surround space constants, etc. The simulation result shows better performance as compared to these methods without optimization and this algorithm also gives better performance as compared to other techniques such as histogram equalization, filtering, etc.

Zhou et al. [30] proposed an image enhancement technique based on fuzzy logic in which parameters or features are optimized using genetic algorithm. In this technique an image is first of all transformed into spatial domain and further fuzzy rules are designed on these domains. Then fuzzy rules are optimized using genetic algorithm. And lastly the image is restored back into image from fuzzy domain using defuzzification and thus enhanced image is formed. The experimental results shows enhanced performance with respect to existing algorithms.

Park et al. [32] presents an automatic double encoder network model based on Retinex theory that allows the improvement and reduction of noise in low light conditions by combining stack and convolution-based auto-encoders. The proposed method first estimates the spatially uniform lighting component, which is brighter than an input image in low light conditions, using a stacked autoencoder with a small number of hidden units. Next, we use a convolutional autoencoder that processes 2D image information to reduce amplified noise in the brightness enhancement process. We analyzed and compared the roles of stacked and convolutional automatic encoders with the conditions of the variant Retinex model. In the experiments, we demonstrate the performance of the proposed algorithm by comparing it with the known methods of the prior art for improving light and contrast.

III. Methodology

In order to gain above mentioned objectives, images are collected with low contrast image sequences of natural scenes.

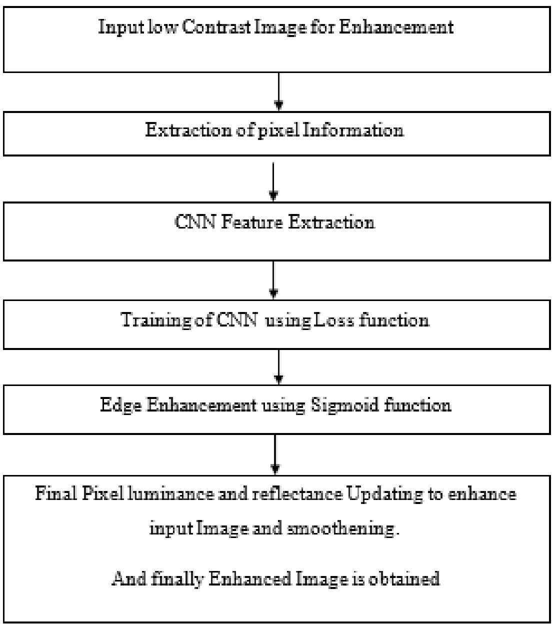

Figure 1: Flowchart of Proposed Methodology

Following Steps are performed while enhancing the contrast of images:

Step 1: Input the low contrast image

Step 2: : Extraction of Pixel Component out of low contrast image

Step 3: Training the proposed CNN network and generate CNN features with smallest DSSIM loss function

Step 4: Updating of low contrast image pixel intensity as well as global gradient value according to CNN features and smoothening with edge aware filtration method.

Step 5: Evaluation of Performance Parameters such as SSIM, FSIM and PSNR values.

The details of all the steps are described as follows:

A. Data Collection

In order to design robust and efficient low contrast image enhancement technique, it is required to collect input images from real-world natural scene. In this research, different image sequences are collected from different camera and collected as a common dataset. For creating low contrast image dataset, the exposure value of the camera are set and collected different sequences of indoor and outdoor scenes. After collecting the low contrast input images, under exposed and over exposed images are created by manipulating the exposure value and save as a reference images.

B. Deep Image Enhancement

The traditional image contrast enhancement techniques is based on histogram equalization which increases the intensity value of the pixels by distributing or equalizing the intensity value of image according to the neighboring pixel values. This illuminates the intensity value of the low contrast image.

However, these algorithms are not quite efficient to generate high quality image with respect to low contrast images just due to complex background intensity values in the natural scene images. This work is performed in two steps. In first step CNN is used to update the pixel intensity values and further edge aware filter is used to preserve the edges and its properties, finally enhanced image is obtained.

To combat the issues of fully connected neural network, convolutional neural networks (CNNs) were created and will be used as the foundation of this dissertation. These are a type of neural network which is designed specifically to be used with images, and differ slightly from traditional neural network structure. Another key property of CNNs is that they are not fully connected, where every node in a layer is connected to every node in the previous layer. There are four main elements to a CNN:

- Convolutional layer
- Rectified Linear Unit
- Pooling layer
- Fully connected layer

Stride Convolution: The feature map generated according to the network is reduced by the convolutional operations. Padding is done to the output images before performing convolution, as output image has to be of same size as that of input image [5]. But this padding may cause artifact in the input image. So, this network is designed with deconvolution layer to make the output size be similar to input size. This deconvolution layer not only decreases the artifacts as well as reduces the computational overhead by applying filters.

Rectified Linear Unit: Rectified Linear Unit (ReLU) are used in many CNN architectures as an activation function for the network. In this activation function, the negative co-efficient are replaced with zero value which is represented by the local features of the input image. The function is represented as:

$$f(x) = \begin{cases} 0 \; for \; x < 0 \\ x \; for \; x \geq 0 \end{cases} \qquad (1)$$

Some of the neurons dropped because they do not contribute to forward passage and do not participate in backpropagation. Every time an input is presented, the neural network analyzes another architecture, but all these architectures share a common weight. This technique reduces the complex adaptations of neurons because a neuron cannot rely on the presence of some other neurons.

Pooling Layer: The pooling layer is used only to reduce the dimensionality of the previous level so that it is more suitable for the next level of the network. This is generally done with the maximum grouping, in which the maximum value of the window that the filter is observing is folded on the image. A CNN can have an unlimited number of convolutional and pooling levels in any order, the only limit is the power and time of calculation and the risk of overfitting of network.

Fully-Connected Layer: The fully connected layer of CNN is a normal neural network and is generally used as a last step in a convolutional network. Generally, it is used for classification purpose where the desired output is an array of elements m (where m is the number of categories is of images) which contain the image probabilities of a given category. In this work, it is used to classify the pixels into road candidates or non-road candidates.

C. Proposed CNN Network Architecture

Table I shows the CNN model configuration.

Table I: Proposed CNN Model Configuration

Layer	Filters	Kernel Size	Stride	Output size
Conv	96	11*11	4	11*11*96
Pooling	N/A	3*3	2	N/A
Conv	256	5*5	1	5*5*256
Pooling	N/A	3*3	2	N/A
Conv	384	3*3	1	3*3*384
Pooling	N/A	3*3	2	N/A
Conv	384	3*3	1	3*3*384
Pooling	N/A	3*3	2	N/A
Conv	256	3*3	1	3*3*256
Pooling	N/A	3*3	2	N/A
Fully connected	N/A	N/A	N/A	3*3*256

During training of the network, the weight functions are updated according to loss function. The loss function used here is stated as:

$$DSSIM(W) = \frac{1}{N}\sum_{I}^{n}(1 - ssim(I_{ref}^{i} - H(I^{i}, W)))/2 \qquad (2)$$

Where, SSIM= Structural Similarity

D. Edge Enhancement using Sigmoid function

After CNN enhancement edges are required to enhance for more smoothning. The intensity and gradient values are updated. So, weight is updated in two steps:

- In first step pixel intensities are updated
- In second step global gradients are updated

Low-light images can be generally divided into two categories: global low-light images and local low-light images. Typical global low-light images are mainly generated by low illumination, whereas local low-light images such as backlight images are due to nonuniform illumination.

Equation 3.3 describes the relationship between image irradiance E and pixel values P such that,

$$P = f(E) \qquad (3)$$

Where,

f = nonlinear function

E= irradiance
P= Pixel Value
When the exposure change, the irradiance, E, reaching the camera sensor will change linearly. However, in many real time scenarios, the image intensity P may not change linearly. Therefore, the mapping function between different exposure images may also be a nonlinear function.
With the definitions of above, following equation is evaluated:

$$g(f(E), k) = f(kE) \tag{4}$$

Where,
g = Brightness transformation function
k = Exposure ratio
According to equation 4.2, the scatter of brightness transformation function is obtained with specific exposure ratio k using the equation 4.3:

$$g(I, k) = f(kf^{-1}(I)) \tag{5}$$

Then the enhanced image I_{enc} can be calculated using spline interpolation methods.
Two-parameter model Sigmoid model calculates f(E) as in equation 4.4:

$$f(E) = (1 + a)\frac{E^b}{E^a + a} \tag{6}$$

Where, a and b are the parameters for the model
Then according to Equation 4.2, the Brightness transformation function, g, of Sigmoid is calculated as in equation 4.5:

$$g(I, k) = (1 + a)\frac{k^b I(1 + a)}{(k^a - 1)I + 1 + a} \tag{7}$$

IV. Database Description

The Images were collected from different resources such as :

i. VV: This dataset is collected by Vassilios Vonikakis in his daily life to provide the most challenging cases for enhancement. Each image in the dataset has a part that is correctly exposed and a part that is severely under/over-exposed. A good enhancement algorithm should enhance the under/overexposed regions while not affect the correctly exposed one [33].

ii. LIME-data: This dataset contains 10 low-light images used in [34].

iii. NPE3: This dataset contains 85 low-light images downloaded from Internet. NPE-data contains 8 outdoor nature scene images which are used in [35]. NPE-ex1, NPE-ex2 and NPE-ex3 are three supplementary datasets including cloudy daytime, daybreak, nightfall and nighttime scenes.

iv. DICM4: It contains 69 captured images from commercial digital cameras collected by [36].

v. MEF5: This dataset was provided by [37]. It contains 17 high-quality image sequences including natural sceneries, indoor and outdoor views and man-made architectures. Each image sequence has several multi-exposure images, we select one of poor-exposed images as input to perform evaluation.

V. Performance Parameters

In this research work two performance parameters are used for image quality assessment. These parameters are:

Peak Signal to Noise Ratio (PSNR)

PSNR represents the degradation of the enhanced image with reference images i.e. under exposed and over exposed. It is expressed as a decibel scale. Higher the value of PSNR higher the quality of image. PSNR is represented as:

$$PSNR = 10log10(\frac{(X * Y)}{MSE}$$

Where,

X and Y are height and width respectively of the image.

MSE= Mean Square Error between enhanced image and reference images

Structural Similarity Index (SSIM)

The structural similarity (SSIM) index is a method for predicting the perceived quality of digital television and cinematic pictures, as well as other kinds of digital images and videos. SSIM is used for measuring the similarity between two images. The SSIM index is a full reference metric; in other words, the measurement or prediction of image quality is based on an initial uncompressed or distortion-free image as reference. SSIM is designed to improve on traditional methods such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE). The SSIM index is calculated on various windows of an image.

The measure between two windows x and y of common size N×N is:

$$SSIM\ (x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

Where, μ_x= mean of x

μ_y = mean of y

σ_x^2 = variance of x

σ_y^2= variance of y

σ_{xy}= co-variance of x and y

c_1 and c_2 are variables to stabilize the division with weak denominator

VI. Result Analysis

The experimental result is performed and tested on different exposure images. All these images, are collected from different resources such as some images are of indoor and some are outdoor, with or without a lighting fixture. The under exposed as well as overexposed images are created for references. After result analysis, the proposed method is compared to the existing methods on the basis of image quality measure such as SSIM and PSNR. Table II shows some examples of low contrast images and enhanced contrast images that verifies the effectiveness of the proposed algorithm.

Table II: A Sequence with Low Contrast and Enhanced Images

Low Contrast Image	Enhanced Image
	
	
	

	
	

In [32] author presented an automatic double encoder network model based on Retinex theory that allows the improvement and reduction of noise in low light conditions by combining stack and convolution-based auto-encoders. Table III, Figure 2 and 3 represents the comparative performance of proposed work with existing work.

Table III: Comparative Performance Evaluation of SSIM and PSNR Values

Techniques	SSIM	PSNR
Proposed	0.88	18.15
Park et al. [32]	0.7044	17.02

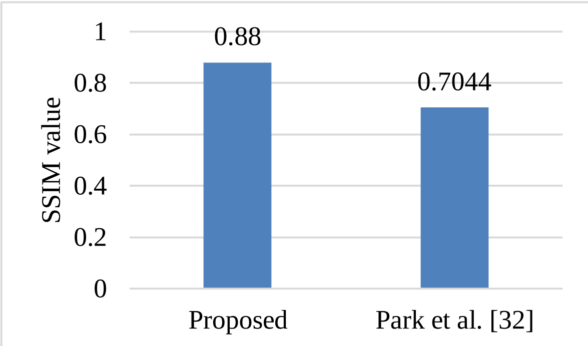

Figure 2: SSIM Comparative Performance Evaluation

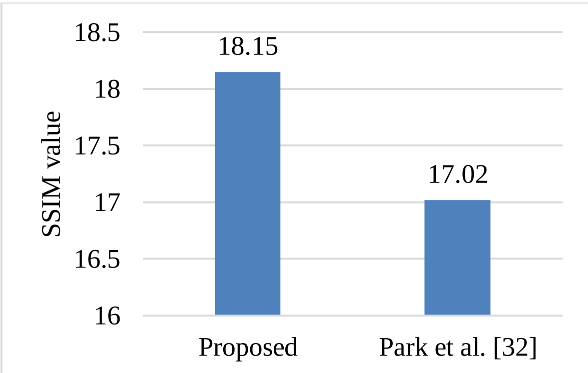

Figure 3: PSNR Comparative Performance Evaluation

VII. Conclusion

In this research, work is focused on designing of low light image enhancement technique. For this dataset is taken with different natural scene images. For processing, a high-quality reference image is generated and used for enhancement of the input low contrast images. Test is also conducted for various input images. The proposed work developed using Deep Edge contrast enhancer (DECE). By applying CNN and Edge Enhancement using Sigmoid function technique, the input low contrast images are capable to adapt according to high quality enhancement. The experimental result is performed on different images, are collected from different resources such as some images are of indoor and some are outdoor, with or without a lighting fixture. After result analysis, the proposed method is compared to the existing methods on the basis of image quality measure such as SSIM and PSNR values. It is observed that average SSIM obtained is 0.89. Similarly, average PSNR obtained is 18.69. The result analysis shows that the developed DECE significantly outperforms better as compared to existing work about 1-2%.

In image processing applications, one of the main preprocessing phases is image enhancement that is used to produce high quality image or enhanced image than the original input image. These enhanced images can be used in many applications such as remote sensing applications, geo-satellite images, etc for future work. The quality of an image are affected due to several conditions such as by poor illumination, atmospheric condition, wrong lens aperture setting of the camera, noise, etc. So, such degraded/low exposure images are needed to be enhanced by increasing the brightness as well as its contrast and this can be possible by the method of image enhancement.

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