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An Approach for Automatic Colorization of Grayscale Images

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Abstract: ***In this paper a novel approach for colorization grayscale images is proposed. The proposed technique colorizes grayscale images using a reference color image that has a similar "mood". A feed forward artificial neural network (ANN) is used. The proposed technique contains two stages, first one is training stage where the system use the reference image to train the system. The output of this stage is three trained neural networks. The second stage is the coloring stage where the system uses the three trained neural networks to color the input grayscale image. Peek Signal Noise Ratio - PSNR quality measure is used to evaluate the proposed technique, and the results showed that typical values for the PSNR which it is between 30 and 50 dB is achieved for recolored grayscale images using proposed technique.***

Keywords: Color Images, Colorization, Gray Scale Images, Neural Network

1. Introduction

Colorization of Gray image is a new image processing area, and although a lot of trials for manual gray images colorization were discovered in 80's, researches for automatic colorization started in the last few years. A lot of techniques come out in the literatures and the number of researches and technologies are increasing every day. The researchers in the last few years tried to find more applications for colorization technology, not only setting colors to uncolored images (Colorization), but also remove colors from the color images and videos (Decolorization) and back to color them to get profits from gray images and videos attributes. Colorization can be categorized into three classes: the first one is Hand coloring, the second one is Semi automatic coloring, and the third one automatic coloring[1].

Gray image colorization or "coloring" means to set colors to grayscale images. It is a new study point area because it is used to increase the visual appeal of images such as old gray images, movies or scientific illustrations. In addition to this, the information content of some scientific images can be perceptually improved with color by exploiting differences in chromaticity as well as luminance. The general issue of adding color to a grayscale image has no accurate and objective solution, because one single grayscale value may match to a range of different colors. Because it is well-known that the gray image loses the facts of its actual color, and because of the gray bandwidth consists of 256 colors only while a bandwidth of the actual color is 256×256×256, it is not possible to discover a direct way to get the exact color back. [1].

Colorization is the process of transferring a gray scale image into RGB color image. Colorization of an image is an issue that was widespread for a very long time, but only recently people have started working in it. The aim of colorization is to convert a gray scale image with 256 shades to a color image with 256x256x256 which contains all the colors.[2]

The problem related with colorization is that several colors have mapped to the similar gray shades. So it is difficult to distinguish whether the given gray shade is of which color. In colorization it is possible to classify different colors that have the same gray scale and so it is simple for analyzing the image.[2]

Gray-scale image colorization is an application for several purposes such as coloring black and white videos or restoring old image. Colors are setting to gray images to improve the visual appeal of images such as black and white photos, classic movies or scientific diagrams. The job of colorization a gray image consists of assigning three dimensional (RGB) pixel values to an image which varies along only one dimension (luminance or intensity). The easiest method proposed by Gonzalez et. al. is pseudocoloring of gray images.[3]

Automatic image colorization consists of setting colors to a grayscale image without user's interference. The problem is that no one can guess the colors to allocate to a grayscale image without any previous knowledge, several objects can have different colors: not only artificial, plastic objects can have unsystematic colors, but natural objects like tree leaves can have different nuances of green and change to brown during autumn, without change of their shapes. A several colorization methods consist of allowing the human to determine the color of a few areas and then spreading this information to the entire image, this can be done by pre-computing a segmentation of the image into identical color areas, or by extending color flows from the color points.[4]

In order to explain the problem of coloring, there are two equations to describe the gray (Gr) value as an equation of the three basic components of RGB color model (red (R), green (G), and blue (B)) :

1: Luminance (NTSC standard):

$$Gr = 0.299R + 0.587G + 0.114B \quad (1)$$

2: Intensity (most common used):

$$Gr = \frac{(R+G+B)}{3} \quad (2)$$

Eq.1 and eq.2 are irreversible, so any gray value can't be switched back to its red, green, and blue components.

because the probable number of colors are (256×256×256), there exist 256×256 combinations of various colors for each gray value from 0 to 255. For instance, figure 1 and table 1 show an example of different colors that have the same gray value.[5]

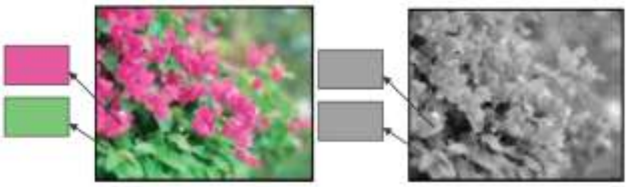

Figure 1: Comparison between Color image and gray images [6]

Table 1: Examples of different colors with the same gray level [5]

RGB Color	R, G, B values	Gray value	Gray Color
	100, 150, 87	128	
	147, 87, 149	128	
	149, 147, 87	128	

In computer graphics, two approaches are used to colorize grayscale image : user-guided edit propagation approach and data-driven automatic colorization approach. In the first approach user tries to draw colored strokes over a grayscale image. Then a colorized image that matches the user's scribbles is generated using an optimization procedure. This approach requires intensive user interaction. Researchers discovered data-driven colorization methods which colorize a grayscale image by two ways: by matching grayscale image to a sample color image from a database or by learning parametric mappings from grayscale to color from large-scale image data.[19]

2. Related Work

Larsson G. et. al. proposed a fully automatic image colorization system that shows state-of-the-art ability to colorize grayscale images. The proposed system used a deep neural architecture which is trained end-to-end to incorporate semantically meaningful features of varying complexity into colorization, also the purposed system used a color histogram prediction framework which treats uncertainty and ambiguities inherent in colorization while preventing jarring artifacts. Larsson G. et. al. proposed a new large-scale benchmark for automatic image colorization, and prepared a strong baseline with their method to facilitate comparisons.[16]

Zezhou C. et. al. developed full-automatic colorization technique by using deep neural networks to decrease user effort and the dependence on the example color images. Informative yet discriminative features including patch feature, DAISY feature and a new semantic feature are extracted and used as the input to the neural network. The output chrominance values are further filtered using joint bilateral filtering to guarantee artifact free colorization quality. The experiments show that this technique outperforms the state-of-art algorithms both in terms of quality and speed.[17]

Tung N. et. al. presented a reliable method for colorizing grayscale images that uses a convolutional neural network to extract color information from an image and transfer to another image. The proposed technique separate content and style of different images and recombine them into a one image by using a pre-trained convolutional neural network that designed for image classification, then color grayscale image using a color image that have semantic similarity with the grayscale one.[18]

S. Guadarrama et. al. presented an approach to automatically colorize graysclae image. In their approach, a multiple colorized versions of a grayscale image is produced. Firstly conditional PixelCNN is trained to generate a low resolution color for a given grayscale image. After that the generated low-resolution color image and the original grayscale image are used as inputs to train a second CNN to generate a high-resolution colorization of an image.[20]

Y. Khalil and P. Ali proposed a new method that colorize a grayscale images. The suggested method color gray images by taking colors from a reference color image to a destination grayscale image. They established a feed forward artificial neural network (ANN) and mapping the pixels from a grayscale space of the reference image that has the same destination grayscale image to train the ANN. There are two main steps. Step one is establishing the (ANN) and training it. The second step is the coloring phase of the gray image by using the trained neural network. The results displayed color images in an appropriate and very distinct look. The gray intensity of each pixel, average and standard deviation values of the intensities of the 8 -surrounding pixels is three information from the grayscale image version are used versus the three components (RGB) form the color version. The proposed method affords a high flexibility to users to select colors and source images as they favor, also the best colored image can be selected among many options[1]

K. Qureshi and C. Vanmathi presented a technique which utilized correct color image colorization with 256x256x256 image which has all the colors. Colorization process has three main phases. The first one is to discover the source image from the database of image by using content based image retrieval system. The second phase is to get the pixel that matches the reference color image to the target gray scale image. The third phase uses 256x256x256 correct color image to look for and get the best similar pixel value and this step is used just when no pixel value found from the source image.[2]

A. Sousa et. al., proposed a method, through machine learning techniques, to give beauty and understandable colors to gray scale images, using a color map chosen from a similar training image. Their method applied the former approach : it analyzes the color content of a given training image, and then tries to expect colorization for a single gray image on a per-pixel basis. While segmentation procedures have real appeal, and could generate in more-consistent colorization, these methods depend on precise image segmentation, which can be thrown off by shadows, texture, or color gradients. Furthermore, methods need subsequent manual identification of the objects in a scene – couch, chair, etc. – for which training color sets are then chosen.[7]

S. Kumar and D. Singh have colorized gray scale images of different sizes in lαβ color space. They acquire a reference colored image which have same texture to the target gray scale image. The quality of coloring based on the selection of reference image. They transfer the target and reference images in lαβ decorrelated color space and break up these images in pieces of the same size. Then a luminosity measure depends on mean and standard deviation that are computerized for each of these pieces. Again texture features like energy, entropy, contrast, homogeneity and correlation depend on correlation matrix are computerized for each of these features are weighted properly and then a texture similarity measure computed for each pieces. Then each of the pieces in target image is compared with every pieces in reference image and the best matching pieces is discovered. After that, a number of data points is selected randomly from the reference image piece using jitter sampling and the chromatic values of these pixels in reference image piece are transferred to the pixels of gray image piece, depend on the mean and standard deviation computations for luminance mapping. [8]

Y.Rathore et. al. (2010), presented a method for setting colors to grayscale images without human intervention. the method needs only to give a target gray scale image, a colored image of the related content as the grayscale image is automatically get back from the database of images, as an input reference image. Then, the best matching source pixel is found out using luminance and texture matching process, for each pixel of the gray image into a perceptually de-correlated color space. Once a best matching source pixel is detected, its chromaticity values is setting to the target pixel while the original luminance value of the target pixel is kept.[3]

F. Pierre et. al., (2014) presented a new variational framework for exemplar-based image colorization in RGB. by using directly these three RGB channel, their model does not require any pre or post-processing procedure. a primal-dual is designed like technique that solves the proposed variational approach. The constraint when coloring a gray-scale image is to save its luminance is added in the variational model. [9]

D. Hyun et. al. (2012), presented a priority-based image and video colorization technique by using a Gaussian pyramid of gradient images. first a user scrawled color sources on a grayscale image, then makes the Gaussian pyramid and computes the priorities of non source pixels at all levels of the pyramid. after that beginning from the highest level, at each level, the presented technique repeatedly allocates the colors to the region of the highest priority. In this way, this technique colors large smooth regions first and small detailed regions later, giving accurate and reliable results. [10]

S. Liu and X. Zhang (2012), proposed an automatic grayscale image colorization algorithm depends on histogram regression. A reference image is selected to provide the color information. Weighted regression is performed on both the grayscale image and the source image. Thus, the property distributions of two images can be obtained. Then, a novel matching technique is presented to align these properties by finding and adjusting the zero-points of the histogram. The grayscale image is colorized in a weighted way when the luminance-color correspondence was accomplished. [11]

S. Liu and X. Zhang (2013), presented an automatic texture-map-based grayscale image colorization technique. The texture map is created with bilateral decomposition and a Gaussian high pass filter, which is optimized using statistical adaptive gamma correction technique. The segmentation of the spatial map is performed using locally weighted linear regression on its histogram to match the grayscale image and the reference image. Within each of the spatial segmentation, a correspondence of weighted color-luminance is accomplished by the results of locally weighted linear regression. The correspondence of luminance-color between the grayscale image and the reference image can be used to colorize the grayscale image directly. [12]

Y. Liang et. al (2014), produced a novel probabilistic framework upon Maximum A Posteriori (MAP) evaluation to transform the given gray scale facial image to corresponding color one without human intervention. Initially, the enter image is split into a number of patches and non-parametric Markov random field (MRF) is working to formulate the global energy. Then, Locality-constrained Linear Coding (LLC) learned the color distribution for each patch. Simultaneously, the simulated annealing algorithm update the patches chosen by LLC to optimize the MRF by minimize global energy cost. The results show that the produced framework is useful to colorize the gray scale facial images. [13]

3. Structure of used Neural network (FFNN)

The proposed approach uses feed forward neural network (FFNN) type of learning because of its simplicity and because it has small error rates, this method-FFNN- use threshold activation function to generate desired output, it can be single layer with one or more output neurons connected with weighted inputs, input of the activation function is the summation of weighted inputs and bias, and the output of the network will be formatted by applying the activation function on this summation.

4. Proposed Colorization Algorithm

In this section, we will present our proposed automated coloring system. Figure 2 shows the general form of colorization system; the system is composed of two main stages: Training stage and Coloring stage. In the following sections, we will describe the construction of each of these stages in details.

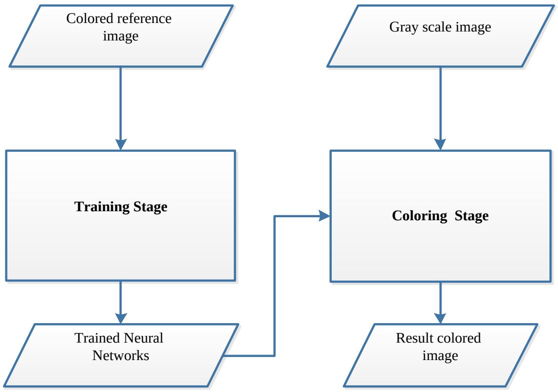

Figure 2 : Colorization system general form

a) Training Stage

In the training stage FFNN technique trains the system using reference colored image which has the same mood of the grayscale image, the output of this stage is three trained neural networks. The figure 3 shows the steps of the training stage.

In this stage, and at the stage; the user selects reference colored image, the reference colored image must have the same mood of grayscale image. the mood of the reference image is important to get the best results. Then the system reads the input reference image and takes grayscale copy from it; to use it in training neural networks. the system converts grayscale copy and original reference image from unit8 to double, because the neural networks contain equations and weights which deal with double values. After that the system exports red, green and blue layers from original reference image and reshapes exported layers and gray copy matrices from (M X N) to (1 X M*N), because the neural network works with one dimensional matrices. Then the system builds and initializes three Neural Networks; the first one for red layer, the second one for green layer and the third one for blue layer. Finally, the system starts training the neural networks, and prepares trained neural networks to use it in colorization stage.

b) Coloring stage

In this stage, the system starts to color grayscale image using three trained neural networks (Red NN, Green NN and Blue NN) which built and trained it in the training stage, the figure 4 shows the steps of Coloring stage.

In this stage, first the user selects the grayscale image that he want to color it and enter it to the system. After that the system reads the input image and converts it from unit8 to double because as we mentioned previously that neural networks contain equations and weights which deal with double values. Then the system reshape grayscale matrix from (M X N) to (1 X M*N) because the neural network works with one dimensional matrices. the system starts coloring the input graysclae image using trained neural networks which the system prepared in training stage, three new layers for red, green and blue colors are produced. After that system reshapes three layers matrices from (1 X M*N) to (M X N) and merges it to form RGB image. the system converts RGB image from double to unit8 and displays the result Colored Image.

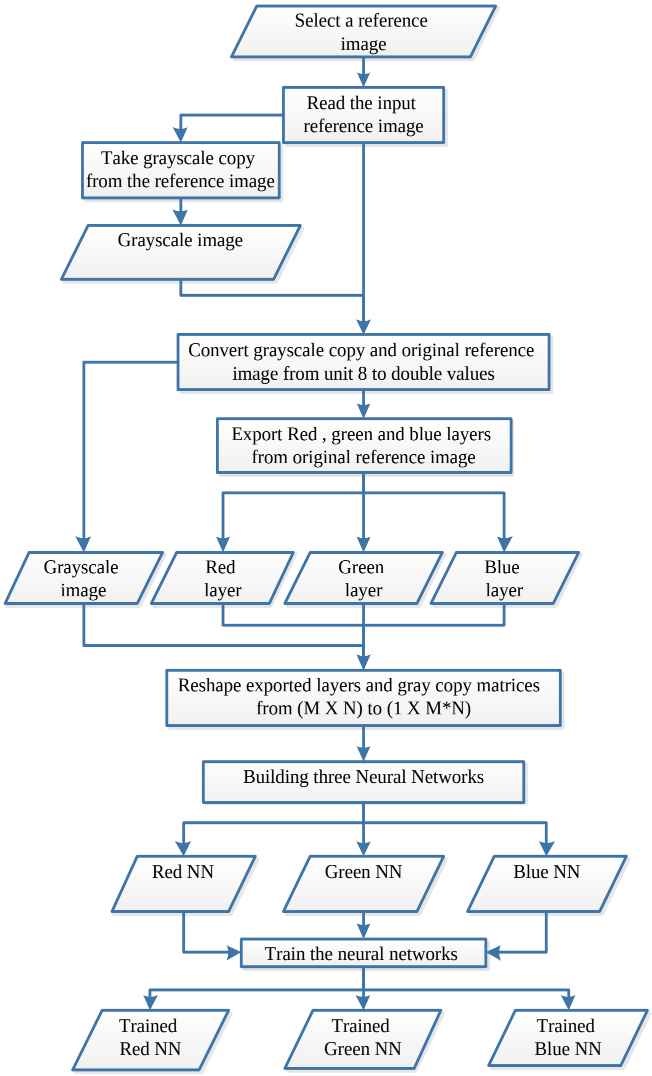

Figure 3: **Training Stage**

5. Experiments and Results

A. Experiments

In this section we try to color some sample of gray scalar images and the outputs are shown in Figure (5). Column (a) is the destination grayscale images to be colorized, column (b) is the colored images that it is used as a reference image ,the system using this image in training stage, after that the system go through coloring stage and the output of this stage is colored image in column (c).

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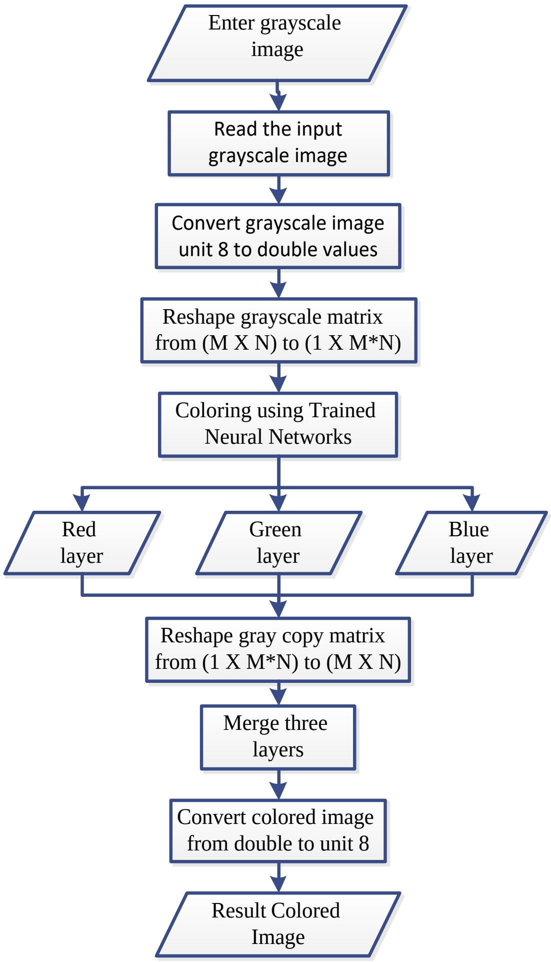

Figure 4: Coloring Stage

6. Results

Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) is most popular of the common full reference (FR) image quality measures used to evaluate most image processing algorithms [6].

Mean Square Error

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (x_{ii} - x_{ij})^2 \quad (3)$$

Peak Signal to Noise Ratio

$$PSNR = 10 \log \frac{255^2}{MSE} \quad (4)$$

During the last 20 years, MSE and PSNR are the most widely used image quality metrics because they are simple and mathematically easy to deal with for optimization purpose.

Peek Signal Noise Ratio - PSNR quality measure is used to evaluate this proposed technique.

The phrase peak signal-to-noise ratio (PSNR), is an engineering phrase for the ratio between the value of the maximum possible power of a signal and the value of the power of corrupting noise that affects its representation. PSNR is usually expressed in phrase of the logarithmic decibel scale, because many signals have a very wide dynamic range.

The PSNR is used as a measure of reconstruction quality of image compression. The signal in this situation is the original data, and the noise is the error came in by compression.

When comparing compression codes, the PSNR is used as an estimation to human perception of reconstruction quality; for that reason in some situations one reconstruction may appear to be closer to the original than another, even though it has a lower PSNR (a higher PSNR would normally signify that the reconstruction is of higher quality). [14]

Typical values for the PSNR in image and video compression are between 30 and 50 dB, where higher value is better. And about 20 dB to 25 dB are a suitable values for wireless transmission quality loss. The MSE will be zero When the two images are the same. For this value the PSNR is undefined.[15]

To evaluate our system, A comparison between original colored image and the recolored image using the original colors of the image, was performed using the ***Peek Signal Noise Ratio*** - PSNR quality measure, the below tables show examples of coloring image using the original colors of the original image.

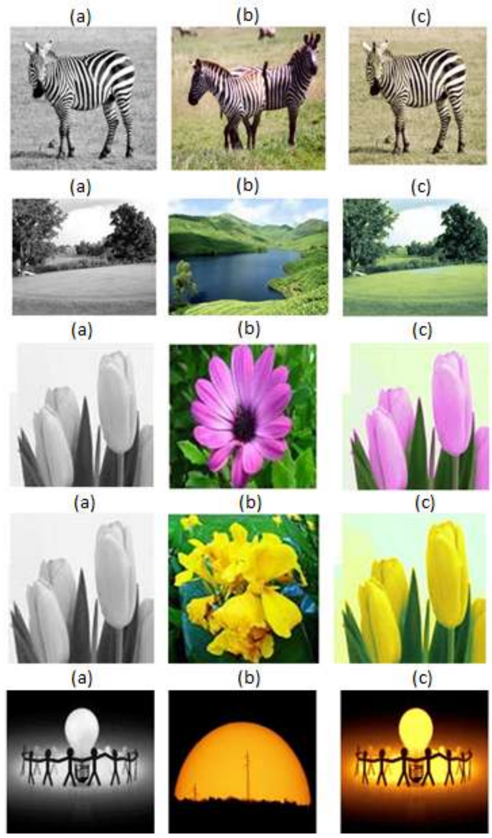

Figure 5: EXPERIMENTS (a) Gray image (b) Reference image (c) colored image

Table 2: Examples of coloring images using original image (Group A)

Original image	Grayscale image	Recolored image	PSNR
			PSNR = 36.40
			PSNR = 31.52
			PSNR = 29.7575
			PSNR = 30.96

Table 3: Examples of coloring images using original image (Group B)

Original image	Grayscale image	Recolored image	PSNR
			PSNR = 32.23
			PSNR = 34.04
			PSNR = 32.59
			PSNR = 31.55

Table 4: Examples of coloring images using original image (Group C)

Original image	Grayscale image	Recolored image	PSNR
			PSNR = 34.36
			PSNR = 37.26
			PSNR = 32.86
			PNSR = 42.21

As shown in the previous tables 4.3 (A ,B and C) , the most PSNR values are fallen in the typical values between 30 and 50 dB, the images that has high PSNR value indicates high quality.

7. Conclusions

This paper proposed a new technique to color gray scale images. This technique consists of two stages: training stage and coloring stage, the neural network has been used in colorization system, the system first trains three neural networks and then uses it to color a grayscale image.

The system was implemented in matlab 10 and tested on different images. PSNR was measured for quality assessment. A comparison between the Original colored image and Recolored Original colored image shows good results, because the most PSNR values are fallen in the typical values between 30 and 50 dB.

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