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Auto Colorization of Gray-Scale Image Using YCbCr Color Space

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Abstract
The process of converting gray images or videos to color ones by adding colors to them and transforming them from one-dimension to three-dimension is called colorization. This process is often used to make the image appear more visually appealing. The main problem with the colorization process is the lack of knowledge of the true colors of the objects in the picture when it is captured. For that, there is no a unique solution. In the current work, the colorization of gray images is proposed based on the utilization of the YCbCr color space. Reference image (color image) is selected for transferring the color to a gray image. Both color and gray images are transferred to YCbCr color space. Then, the Y value of the gray image is combined with the Cb and Cr values of the reference image, based on the Euclidian distance between them. The quality of the resulted image was measured based on several quality measures, which indicated very good results. The proposed algorithm is simple, efficient, and fast.

Keywords: colorization, gray image, image processing, YCbCr color space, image quality.

التلوين التلقائي لصورة التدرج الرمادي باستخدام مساحة لون YCbCr

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الخلاصة
تسمى عملية تحويل الصورة الرمادية أو الفيديو إلى صورة ملونة عن طريق إضافة ألوان لها وتحويل الصورة ذات البعد الواحد إلى صورة ثلاثية الأبعاد. وغالبا ما تستخدم لجعل الصورة تبدو أكثر جاذبية بصريا. المشكلة الرئيسية في عملية التلوين هي عدم معرفة الألوان الحقيقية للكائنات في الصورة عند التقاطها، لأنه لا يوجد حل فريد من نوعه. في العمل الحالي، يتم تلوين الصورة الرمادية المقترحة بناءً على استخدام مساحة اللون **YCbCr**. الصورة المرجعية (الصورة الملونة) المحددة لاستخدامها لنقل اللون إلى صورة رمادية. يتم تحويل كل من الصورة الملونة والصورة الرمادية إلى مساحة اللون**YCbCr** ، ثم دمج القيمة **Y** من الصورة الرمادية مع القيم **(Cb** و **Cr)** من الصورة المرجعية استنادًا إلى المسافة الإقليدية بينهما. جودة الصورة الناتجة تقاس بالعديد من مقاييس الجودة وتعطي نتائج جيدة للغاية. الخوارزمية المقترحة بسيطة وفعالة وسريعة.

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1. INTRODUCTION

Image colorization is a major challenge to researchers, since it is a difficult and ill- posed problem with no unique solution. In automatic colorization, there is no prior knowledge about the origin color for any object or region and, therefore, all the colors are possible to use for coloring them. In colorization processes, we try to assign red-green-blue (RGB) values (3D pixel) to gray value (1D pixel), which is very laborious task. The goal of color mapping is to transfer colors to gray images, or videos, by deriving mapping between that image and another image serving as a reference [1]. In the recent years, researcher gave high attention to these methods in both academic and industrial areas. There are three types of gray image colorizing: Hand coloring, Semi-automatic coloring and Automatic coloring. Hand coloring requires a very large human effort. While in semi-automatic coloring, the user adds points of colors, called scribbles, to the gray image and then the color is spilled over the image according to the indicated colored points. Although efficient and more useful in medical imaging, this method is time consuming. In automatic colorization, there is almost no user intervention. There are many methods used for matching the pixels between reference and gray images [2and many researchers suggested colorizing algorithms. Huang *et al*. [3] suggested to minimize the bleeding of color through the region boundaries and to develop an algorithm based on the detection of the adaptive edge.

Qu *et al*. [4] and Luan *et al*. [5] proposed to reduce the dependence on the scribbles by utilizing some of the image texture. The suggested method is called "the example-based method" which transfers the colors from the color image to the gray one. The suggested method is divided into two classes based on the source of color image. The first class needs the user to provide the color image to use it as reference image. Kuzovkin *et al*. [6] proposed a descriptor-based image colorization. They used a patch match algorithm with a series of statistical descriptors. They also provided a regularization method for removing the artifacts. They computed 38- dimensional descriptors for both reference and gray-scale images by concatenating the texture gradients, HOG (histogram of gradients), and intensity of gray-scale.

Bo-Wei *et al*. [7] introduced a complete procedure using machine learning methods to colorize images. The drawback was that the system still needed to manually designate a reference image that was highly similar to the given one. This would be quite tricky, since some antique images may not resemble the colored ones. It is also inefficient and un-scalable, since a large number of images would require much manual selection. Ibrahim and Sartep [8] proposed an algorithm to transfer colors to grayscale images which is implemented by using two different color spaces (YCbCr and HSV) together with generation of color palette for color source image. Color transfer depends on the comparison between the color palettes of color source image and target grayscale image along with different pixel window size. Liu *et al*. [9] suggested using many colored images, that contain similar objects or scenes, for colorization. The author attempted to increase the accuracy of transferring the color information to the gray image. This method is limited to static objects and scenes and unable to colorize dynamic objects.

Chia *et al*. [10] introduced a framework to select the proper reference images from the set of internet images. This method needs the user to suggest a semantic text label, which is used to search for proper images in the internet. Also, it costs the user efforts to segment the foreground objects from the background scene.

MATERIALS AND METHODS

2.1. YCbCr Color Space

YCbCr is another type of color spaces used in the transformation of images color, which consists of three channels; the Y- channel represents the light or the equivalent of the gray image, while the other two channels represent the color levels of this space. This color space is used to obtain a representation that is more efficient for images. It works by separating the luminance and coloring components in a particular scene and using fewer parts to color the luminance.

The following equations are used for the transformation of RGB to YCbCr [11]:

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

$$Cb = 128 - 0.168736R - 0.331264G + 0.5B \quad (2)$$

$$Cr = 128 + 0.5R - 0.418688G - 0.081312B \quad (3)$$

where $R^`, G^` and\ B^`$ represent pixels in the color image.
By reversing the YCbCr to RGB, we obtain:

$$R = Y + 1.402\,(Cr - 128) \quad (4)$$

$$G = Y - 0.34414\,(Cb - 128) - 0.71414(Cr - 128) \quad (5)$$

$$B = Y + 1.772(Cb - 128) \quad (6)$$

2.2. Performance Evaluation [12, 13]

2.2.1 Mean Square Error (MSE)

The most famous and simplest measure used is the mean square error. It measures the difference between two signals. It is very easy to compute the error in the signal by subtracting the target signal from the source signal. MSE is used in this paper to measure the image quality, where the ideal value of MSE is zero.

$$MSE = \sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j) - C(i,j))^2/M * N \quad (7)$$

where I is the original image, C is the colorized image, and (N x M) represents image size.

2.2.2 Peak Signal-to-Noise Ratio (PSNR)

PSNR is a measure that is used to determine the proportion of similarity or difference between two images of the same structure, where the higher value implies good quality. It is determined by:

$$PSNR = 10\ log10\ (255\ ^2/\ MSE) \quad (8)$$

2.2.3 Root Mean Square Error (RMSE)

RMSE represents the square root for MSE, and its ideal value is zero.

$$MSE = \sqrt{(\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j) - C(i,j))^2/M * N)} \quad (9)$$

2.2.4 Average Difference (AD)

AD represents the average difference between the original color image and the image after coloring, with an ideal value of zero.

$$AD = \frac{1}{NM}\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - C(i,j)] \quad (10)$$

2.2.5 Maximum Difference (MD)

This measure represents the maximum value of the difference between the two images, with an ideal value of zero.

$$\text{MD} = max|I(i,j) - C(i,j)| \quad (11)$$

2.2.6 Structural Content (SC)

SC is one of the measures of image quality, which determines the similarity between the two images and has an ideal value of one.

$$SC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(C(i,j))^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j))^2} \quad (12)$$

2.2.7 Normalized Absolute Error (NAE)

NAE is an image quality measure that determines the extent of difference between images, with an ideal value of zero.

$$NAE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(|I(i,j) - C(i,j)|)}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j))} \quad (13)$$

2.2.8 Normalized Cross Correlation (NC)

NC is a measure that compares the processed and reference images. The ideal value of NC is one, which is expressed by:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j) * C(i,j))}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j))^2} \quad (14)$$

2.2.9 Correlation Coefficient (CC)

CC is a very helpful statistical formula that is used to determine the strength of the relationship between the two variables of images, with an ideal value of one. CC is calculated using the following equation:

$$r = \frac{\sum_1^M\sum_1^N(I(i,j) - \bar{I})\ (C(i,j) - \bar{C}}{\sqrt{(\sum_1^M\sum_1^N(I(i,j) - \bar{I})^2)(\sum_1^M\sum_1^N((C(i,j) - \bar{C})^2))}} \quad (15)$$

where $\bar{I}$ = mean (I) and $\bar{C}$ = mean (C)

2.2.10 Structure Similarity Index (SSIM)

The SSIM index evaluates the gray image with respect to a reference image, to quantify their visual similarity. The ideal value of SSIM is one and the general equation to calculate it is:

$$SSIM(x,y) = [l(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[r(x,y)]^{\gamma} \quad (16)$$

where α, β, and γ are parameters that define the relative importance of each component, and:

$$l(x,y) = (2\mu_x\mu_y + C1)/(\mu_x^2 + \mu_y^2 + C1) \quad (17)$$

$$C(x,y) = (2\sigma_x\sigma_y + C2)/(\sigma_x^2 + \sigma_y^2 + C2) \quad (18)$$

$$r(x,y) = (\sigma_{xy} + C3)/(\sigma_x\sigma_y + C3) \quad (19)$$

where C1, C2, and C3 are constants introduced to avoid instabilities when average pixel value $(\mu_x^2 + \mu_y^2)$, standard deviation $(\sigma_x^2 + \sigma_y^2)$, or $\sigma_x\sigma_y$ are close to zero. The value of SSIM (x, y) ranges from zero (completely different patches) to one (identical patches).

2.3 The Proposed Method

In this proposal, an automatic colorizing process is suggested to colorize the gray image**.** Human intervention in this process is represented only by the selection of the reference image (color image), while the rest of colorizing works are achieved by the suggested software. The proposed algorithm in Table-1 summarizes the steps for colorizing the gray image.

Table 1-The proposed algorithm steps for the colorization of the gray image

Algorithm 1: Colorization of Image
Input: Gray image and RGB image. **Output:** Colorized image. 1. Select color reference image (I) (preferred to have similar features to the target grayscale image (G)). 2. Transform image (I) to YCbCr color space (image IC). 3. Convert the gray image into three layers by repeating the gray image for each layer (image T). 4. Transform image (T) to the YCbCr color space (image TC). 5. Select from location (m, n) of image (TC) the value of pixel in (Y) channel, (scan the entire image (Y channel) from left to right and top to down). 6. Compare the value of pixel selected in step 5 with all values of (Y channel) of image (IC), and at each time find the Euclidean distance between the two values. 7. Find the location (i, j) from image (IC) for the pixel with the minimum distance. 8. Combine the value of (Y channel) of pixel in location (m, n) from image (TC) selected in step 5 with the values of (Cb, Cr channels) of the pixel from image (IC) in location (i, j). 9. Store the pixel value result from step 8 (Y, Cb, Cr) at the new image (IM) at the location (m, n). 10. If the last pixel in the image (TC) is not reached, go back to step 5. 11. Convert YCbCr color space image (IM) to color model image (RGB). 12. Check performance.

The first step is to select a color image (reference image) that is similar in the structure or contents to gray image. Then the reference image is converted to the YCbCr color space and symbolized as (IC). Next, the gray image is converted to the YCbCr color space after repeating the gray image in three layers and symbolizing it as (TC).

For each pixel of image (TC), select the value of (Y) channel and compare it with all the values of (Y) channel in image (IC) (measuring the Euclidean distance).

The pixel from image (IC) with minimum distance to the pixel from image (TC) represents the more similar pixel and can be used to transfer their color information to gray image. The bright value (Y) channel for the selected pixel from image (TC) will be combined with the values of image chrominance (Cb, Cr) of the pixel in image (IC) with minimum distance to the selected pixel. The combined pixel (Y, Cb, Cr) will be stored in new image at the same location (coordinates) of the selected pixel from image (TC). When the entire pixels of (Y channel) of image (TC) are compared, then we obtain a new image with the same size of the gray image in color space (YCbCr). The new image is transformed to the RGB color model, which represents the results of colorization of gray image to colored image. Figure-1 shows the flow chart of the proposed algorithm.

2. RESULTS AND DISCUSSION

The proposed algorithm was implemented with many gray scale images and the results were obtained using several quality measurements (RMSE, PSNR, AD, MD, NAE, NC, SC, SSIM, and CC). Figures- 2, 3, 4, 5, and 6 explain the values of these measurements for the proposed method used for colorizing the images shown in Figure- 7. For accurate measurement of colorization performance, we suggested to select a gray image that is converted from a known color image, which aids to visually compare the colorized image with the ground truth image, by determining these measurements. Figure- 7 shows the results of colorization process for many different images. Visually, the colorized images have good similarity with ground truth image. The colorized images look more pleasant as compared with the gray images. From Figure-2, we observe that RMSE is in a reasonable range (average to equal 10), meanwhile the average PSNR value (about 30 as shown in Figure-2) reflects a very promising result, given the fact that the average PSNR for most similar works is about 22. It is obvious that, when the content of the reference image is similar to that of the gray image, then we obtain very good results, as in image 1 of Figure-7. While when there is a difference in color histogram between the reference image and the ground truth image, then the result is colorizing according to the colors in the reference image, with some possible color deformation, as in image 5 in Figure-2. From Figure-3, we observe that the average value of MD is about 100, representing maximum difference between the two images. This result is normal in the colorization process because it is difficult to achieve the same color of the original image. Time, which is an important factor in the colorization process, showed a very reasonable value, which is in fractions of seconds, except one image which was executed in about one second (Figure-4).

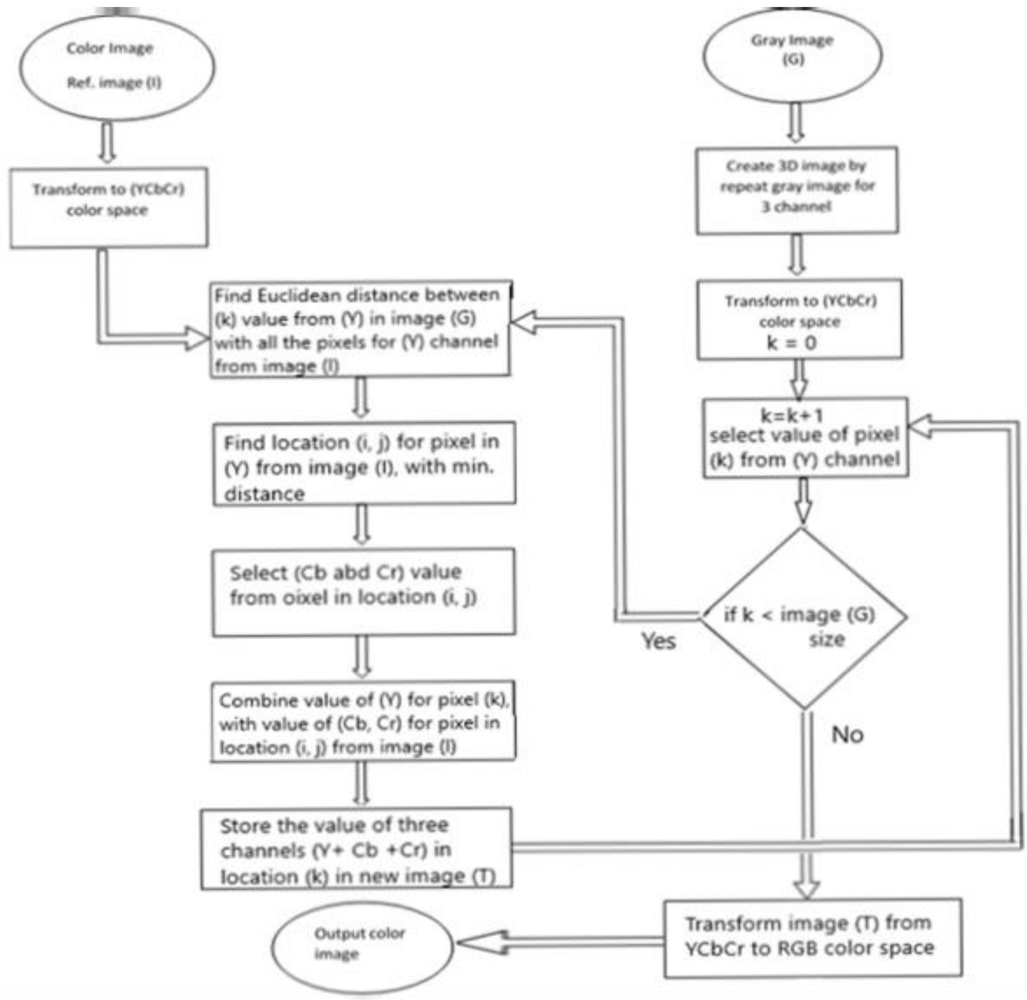

Figure 1-Flowchart of the proposed algorithm

The results of measuring several criteria are plotted in Figure-5. One of those is the structural similarity measure, where a very good similarity between the ground truth image and colorized image was obtained. The second criterion is the measure of the visual similarity by using SSIM. The method showed a very good result which coincides with the visual look to image. Also, very good results for correlation coefficient (CC) were recorded. The last quality measure illustrated in Figure-5 is NAE, which showed a medium extent of difference between the ground truth image and the colorized image. Finally, we measured the quality by using NC and AD, as shown in Figure-6. The result of cross correlation (NC) between the two images was very good. While the (AD) measure of the average difference between the original color image and the image after coloring showed some difference. Although a medium deviation was observed, we believe that this is a normal outcome because it is not possible to obtain the original colors in the blind process of coloring. It is clear that we could achieve very good results according to the quality measures. The colorizing process achieved in this work was compared with that from other works, as illustrated in Figure-8, and showed good results, although it was difficult to compare with more works due to unknown software of algorithms and difficulty of obtaining the same images.

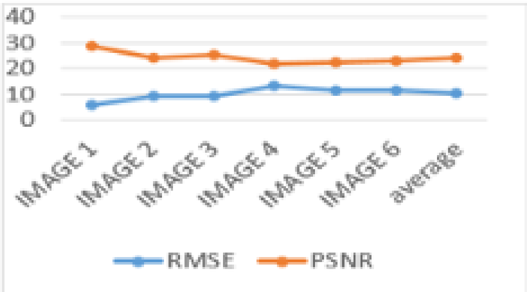

Figure 2: show the RMSE and PSNR for different images.

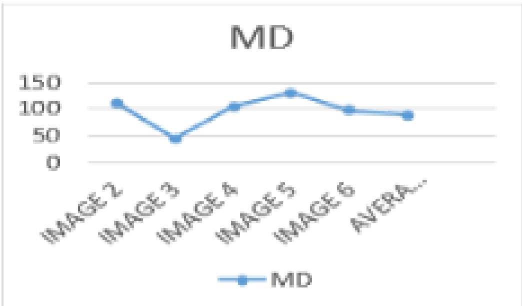

Figure 3: show the MD measure for different images

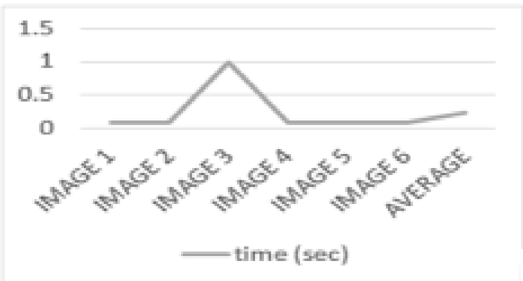

Figure 4: execution time for colorizing many images.

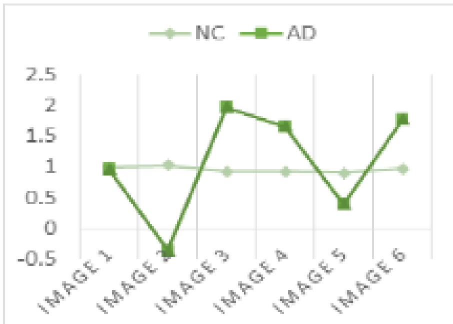

Figure 5: measuring NC and AD.

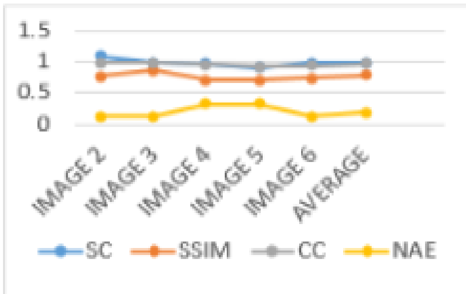

Figure 6: show the NC and AD for different images.

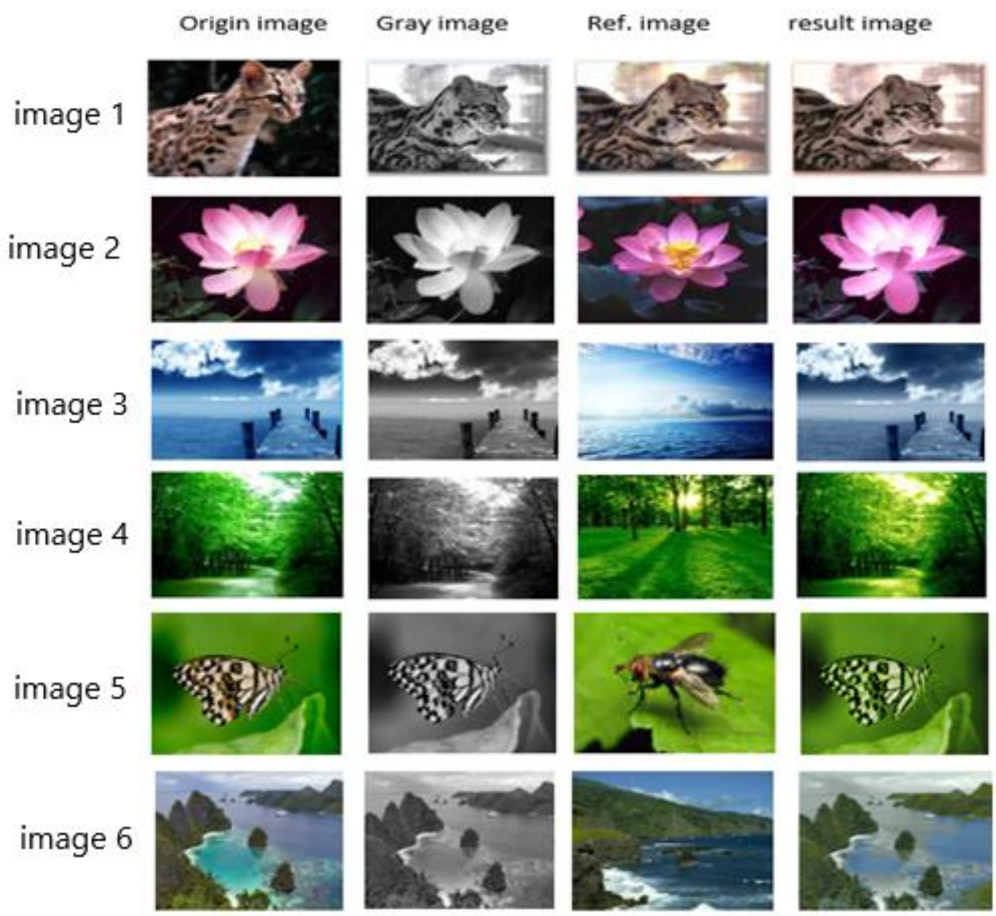

Figure 7- Images colorized by the proposed method.

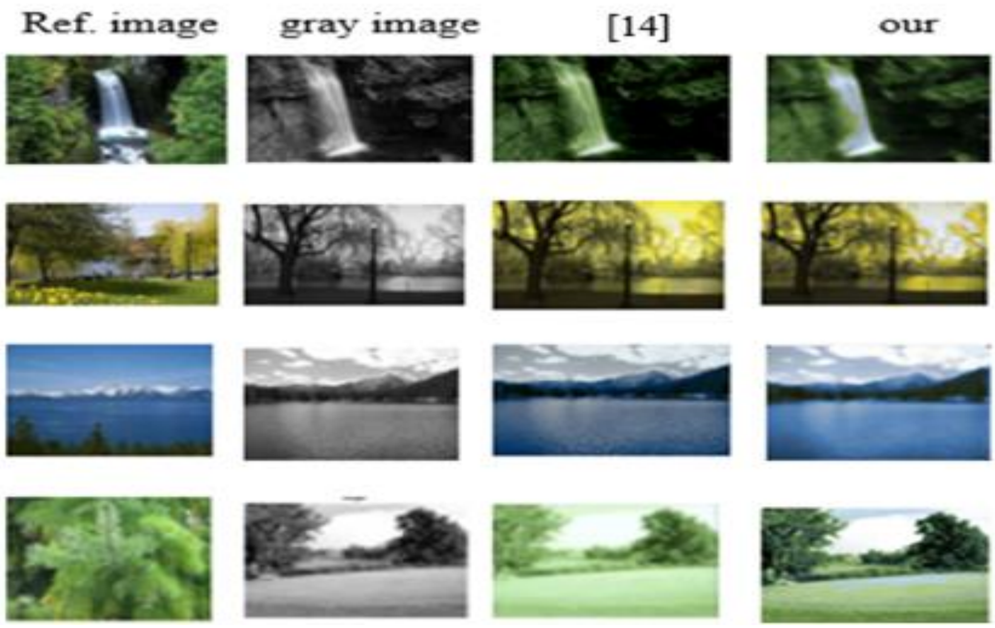

Figure 8- Comparison of our method with Kumar (2012).

3.Conclusion

This work presents a fully automatic method for colorizing grayscale images based on YCbCr color space and a reference image. Quality of the colorized images was measured by using several quality measures, showing very good and promising results. Visually, the colorized image had pleasant appearance and good similarity with the ground truth image. The cornerstone of this method is the need for a reference image containing the same content in the gray image with similar color histogram. It is clear that the colorization of gray images depends on the colors in reference images. Also, selecting a reference image with the same category of the gray image can enhance the colorization process. The proposed method is fast to implement and very simple.

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