A Proposed HSV-Based Pseudo-Coloring Scheme for Enhancing Medical Images

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ABSTRACT

Medical imaging is one of the most attractive topics of image processing and understanding research fields due to the similarity between the captured body organs colors. Most medical images come in grayscale with low contrast gray values; which makes it a challenge to discriminate between the region of interest (ROI) and the background (BG) parts. Pseudo-coloring is one of the solutions to enhance the visual appeal of medical images, most literature works suggest RGB-base color palettes. In this paper, pseudo-coloring methods of different medical imaging works are investigated and a highly discriminative colorization method is proposed. The proposed colorization method employs HSV/HSI color models to generate the desired color scale. Experiments have been performed on different medical images and different assessment methods have been utilized. The results show that the proposed methodology could clearly discriminate between near grayscale organs especially in case of tumor existence. Comparisons with other literary works were performed and the results are promising.

KEYWORDS

Medical imaging, pseudo-coloring, colorization, HSV

1. INTRODUCTION

Medical images not only represent structural appearance information, they are also capable of examining complex and sophisticated internal biological processes. Medical imaging contributes to many disease diagnoses and also plays an important role in understanding the human anatomy which guides surgical assistance during the procedure.

Medical Imaging has various modalities and applications. X-ray, CT, MRI, Ultrasound, Mammogram, Nuclear Medicine, PET, Ultrasound, and Thermal imaging are some of the famous imaging technologies [1, 2]. Each of which has its suitable applications and features and exports gray shades images which usually come in low contrast intensities.

Digital image can be represented in different formats; 1) Grayscale (8-bits/pixel), 2) True Color (24 bits/pixel) and 3) Indexed (8-bits/pixel index image + Color Map) [3]. Medical images usually come in grayscale which has only 256 gray shades variations. While most image understanding researchers prefer to deal with color images instead of grayscale, as the color variations exceed 16 million degrees of colors.

For some imaging technologies, a pseudo-coloring system may be embedded in the imaging device. Pseudo-Coloring gives non-real colors to the grayscale image by converting it to an indexed image with a fixed color map. Generating the color map is the main contribution in this field of research.

There are two approaches for medical images colorization in the literature; semi-automatic (interactive) pseudo-coloring [1] and automatic (non-interactive) pseudo-coloring [4-10].

In this paper, we are concerned with automatic medical images pseudo-coloring. The rest of this paper is organized as follows, Section 2 presents automatic medical colorization literature review. The proposed colorization method is presented in Section 3 in details. Section 4 presents the experimental results and a comparative study of the proposed method and other different methods. Finally, Section 5 concludes this paper.

2. LITERATURE REVIEW

L. H. Juang and M. N. Wub [4] used color-converted segmentation with K-means clustering technique for Brain MRI tumor objects colorization and tracking. Starting with a gray image, the original image was segmented by k-means and mapped colors to the segments by using color-convert which starts by R, G, B then mapped to a single index value. Compare between Otsu segmentation results and claim 96% accuracy and 10 minutes processing time!

M. d. C. V. Hernández et. al. [5] used image fusion between T2W and FLAIR images for differentiating normal and abnormal brain tissue, including white matter lesions (WMLs). They modulated two 1.5T MR sequences in the red/green color space and calculated the tissue volumes using minimum variance quantization. M. Attique et. al. [6] also used image fusion for brain MRI images. They utilized Single slice of T2-weighted (T2) brain MR images using two methods; (i) A novel colorization method to underscore the variability in brain MR images, indicative of the underlying physical density of bio-tissue, (ii) A segmentation method to characterize gray brain MR images.

M. Martinez et. al. [7] proposed their color map for CT Liver images, the ROI is selected manually. Each grayscale pixel was assigned a color value (R, G, B) based on a generated color map. A color scheme was developed where the lowest tissue density value was colored red, blending towards green as the tissue density value increases and continued to blend from green to blue for the next range of increasing tissue densities. An associated segmentation process is then tailored to utilize this color data. It is shown that colorization significantly decreases segmentation time. M. E. Tavakol et. al [8] applied their proposed colorization system on Thermal Infrared Breast Images. Lab color model is considered. Two color segmentation techniques, K-means and fuzzy c-means for color segmentation of infrared (IR) breast images are modelled and compared.

Z. Zahedi et. al [9] proposed their colorization system for breast thermal images as a nonlinear function transforms for pseudo-coloring of infrared breast images based on physiological properties of the human eye. N. S. Aghdam et. al [10] proposed four pseudo-coloring algorithms for breast thermal images. The first two algorithms are in HSI color space and the other two are in CIE L*a*b*.

3. PROPOSED COLORIZATION SCHEME

The proposed colorization system is based on HSV/HSI color models where any RGB color triple value can be expressed in terms of Hue (H) Saturation (S) and Intensity (I or value V). Since the grayscale image has only intensity component and has no hue or saturation values [3], our system is based on generating suitable hue and saturation values for each intensity level. Figure 1 presents the main block diagram of the proposed system.

3.1. Intensity Component Generation

In order to generate a carefully designed pseudo-color coding which could preserve all the information of grayscale images and does not generate any distortion in the image, the grayscale image is loaded and saved as the intensity component for the output image.

$$I = G \tag{1}$$

, where L is the Intensity component in HSV/HIS image and G is the gray image.

3.2. Hue Component Generation

Since the gray image has different gray shades which reflect different medical meanings, it's suggested to use the same varieties for the domain color of each region. Human vision can discriminate between the main Rainbow colors; red, orange, yellow, green, cyan, blue and magenta, which can be generated by Hue component. Hue component reflects the dominant color of the pixel. Here, we studied 3 strategies of generation the Hue component.

A. Equal to Intensity (EI)

In this strategy, Hue is set to the same value of Intensity (2). That makes the shades vary from red to magenta for the gray shades from black to white respectively. For some medical images, the ROI gray shades are in light areas with very close values. By using this strategy the colors of ROI may come in red and magenta which may not be discriminative enough.

$$H_{EI} = G \tag{2}$$

B. Complement of Intensity (CI)

In this strategy, Hue is set to the Intensity complement value (3). That makes the shades vary from red to magenta for the gray shades from white to black respectively

$$H_{CI} = 1 - G \tag{3}$$

C. Stretched Inverted Intensity (SI)

Since the gray levels of medical images are very close, a stretched grayscale image has been generated by contrast stretching function (4). The aim of stretching function is to generate wider color space than the limited gray levels in the source gray image

$$H_{SI} = 1 - \frac{(b-a)}{(d-c)}(G-c) + a \tag{4}$$

, where G is the input gray image. The parameters a and b are the minimum gray level and the maximum gray level in the input image, while c and d are the minimum gray level and the maximum gray level in the desired image respectively.
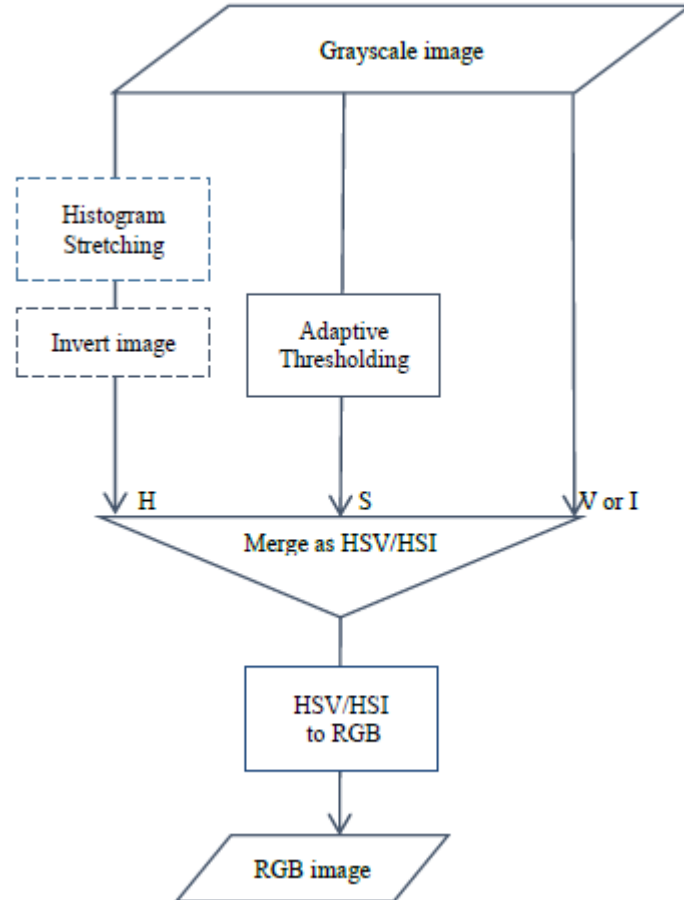

Figure 1. Proposed colorization system

3.3. Saturation Component Generation

For the Saturation component, the original gray image is used again to generate the suitable saturation. Since it is important to see the organs in full clear color, while neglecting the background, an adaptive thresholding [3] has been used to generate a binary image of black background pixels and white foreground pixels (5).

$$S = \begin{cases} 1 & I \geq th \\ 0 & I < th \end{cases} \tag{5}$$

The complete process can be illustrated mathematically by (6).

$$HSL = \begin{cases} H_{SI} = 1 - \frac{(b-a)}{(d-c)}(G-c) + a \\ S = 1 \qquad\qquad\qquad I \geq th \\ S = 0 \qquad\qquad\qquad I < th \\ L = G \end{cases} \tag{6}$$

There is a little difference between HSV and HSI color models; where the pure colors of full saturation are at the top of HSV while they are in the middle at the HSI. In our proposed system, both models are used considering the same transformations (6). Finally, the final RGB color image is generated after the well-known HSV/HSL to RGB conversion [3].

4. EXPERIMENTAL RESULTS

The proposed system has been implemented in MatlabR2013 on 8G-RAM 64bit-OS Windows 8 machine and different medical imaging modalities have been used for testing. A comparison between the proposed coloring system and other systems has been made with regard to different assessment methods.

4.1. Subjective Assessment

Subjective assessment methods are utilized to perform the task of assessing visual quality to the human subjects. This section presents the visual results of the proposed system as well as different literature methods [7-10]. Figure 2.a presents a grayscale image that presents the 256 shades of gray and the color palettes for the methods of [7-10] compared to the proposed method with 6 strategies; (3 for HSV and 3 for HSL). In this example, the saturation threshold has been set to 0.1 for illustration. Figure 3 presents more visual results for different types of medical imaging; Brain MRI, Breast Thermal, Liver CT, and Bone MRI. Generally, it seems that our proposed system could successfully discriminate between the background and the foreground, since it gave colors only to the desired imaged organs. It appears that it gives more details to the images by giving a lot of color verities from hot (red) to cold (blue).

Mean Opinion Score (MOS) [11] is a subjective measure that can be presented in numbers. It measures the users' satisfaction with the visual results. It is calculated by averaging the results of a set of subjective test that gives a score to the results image from 1 (bad) to 5 (Excellent). The mean rate of a group of observers who join the evaluation is usually computed by the following equation:

$$MOS = \sum_{g=1}^{5} g p(g) \tag{7}$$

, where g is grade and p(g) is grade probability. We have performed the MOS test using an online test. 60 volunteers have rated the different 12 methods we presented in this paper by giving them rates from 1 to 5. The obtained MOS is presented in Figure 4.
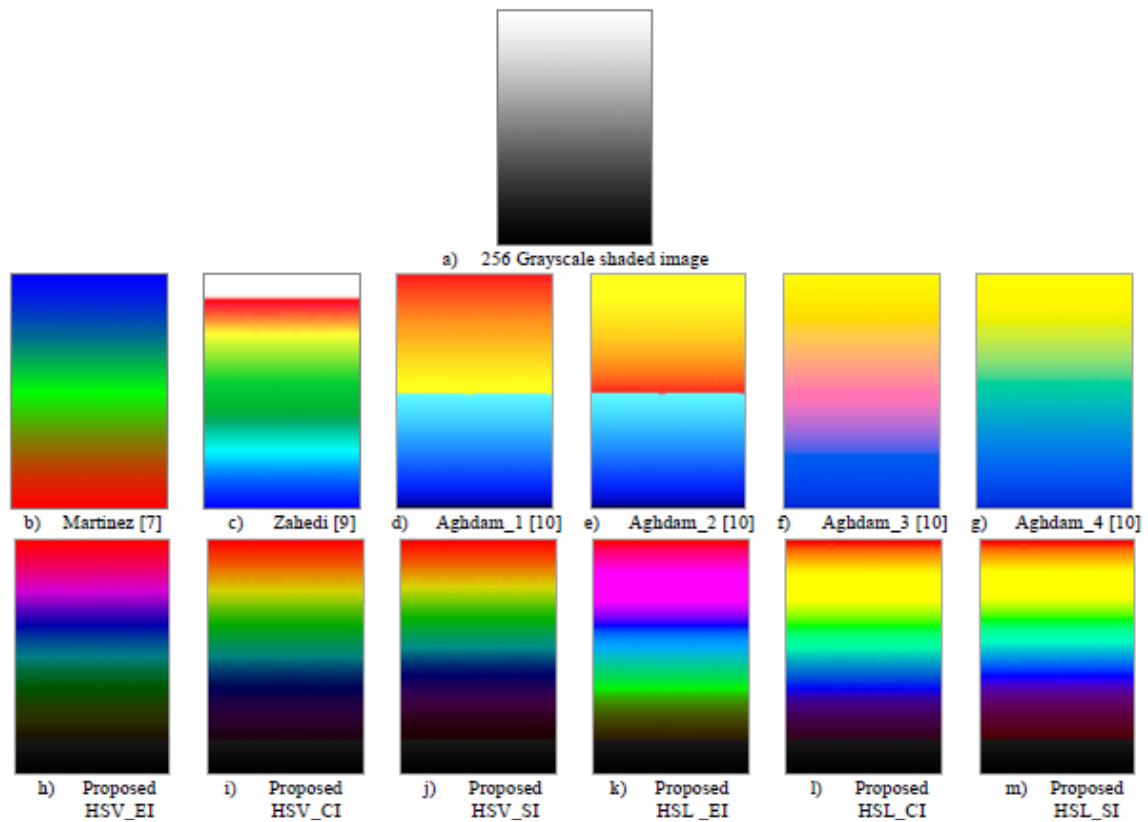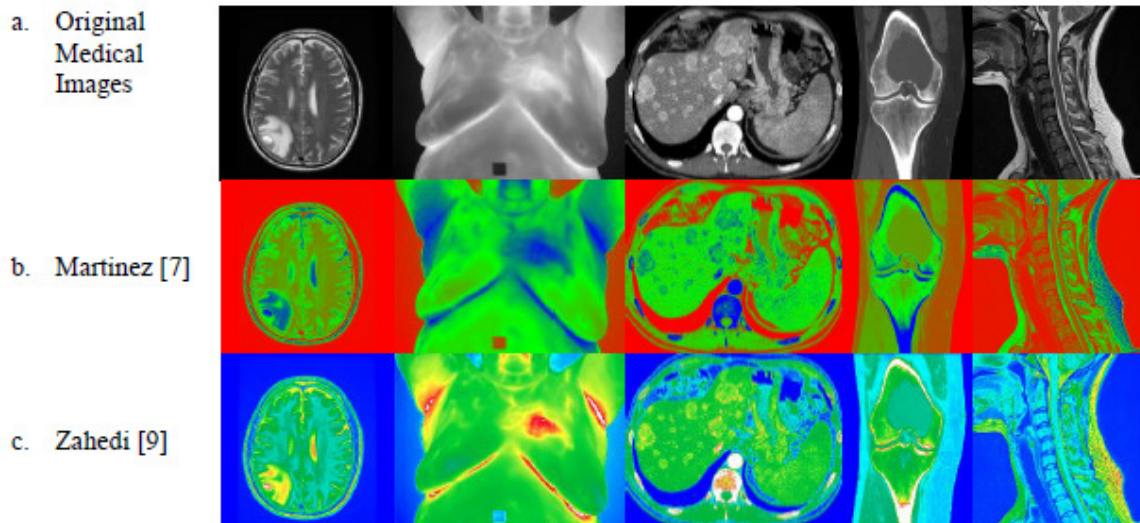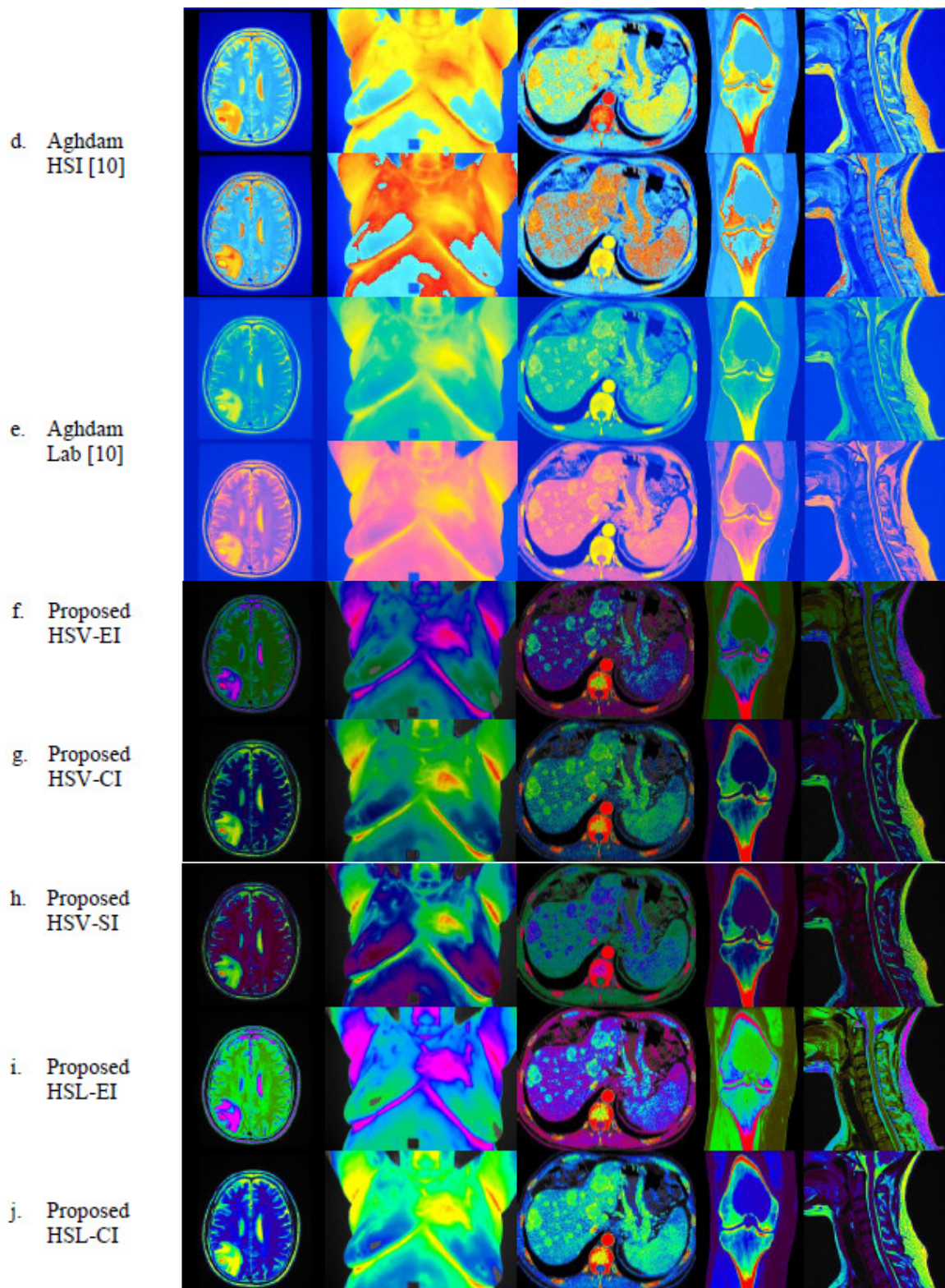
Figure 2. (a) 256 shaded gray palette (b-g) Color Palettes of [7-10] methods and (h-m) the proposed color palette with 6 strategies.

d. Aghdam HSI [10]

e. Aghdam Lab [10]

f. Proposed HSV-EI

g. Proposed HSV-CI

h. Proposed HSV-SI

i. Proposed HSL-EI

j. Proposed HSL-CI
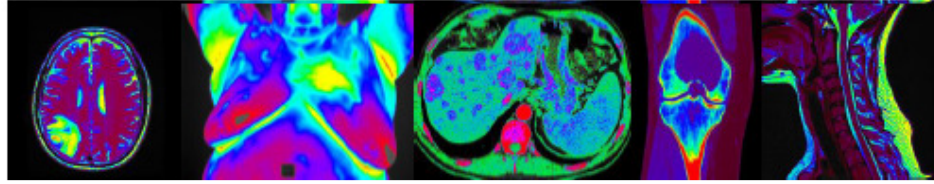
k.   Proposed
     HSL-SI

Figure 3. (a) Original medical gray image (b-e) Visual comparison between literature methods [7-10] and (f-k) the proposed colorization method with 6 strategies
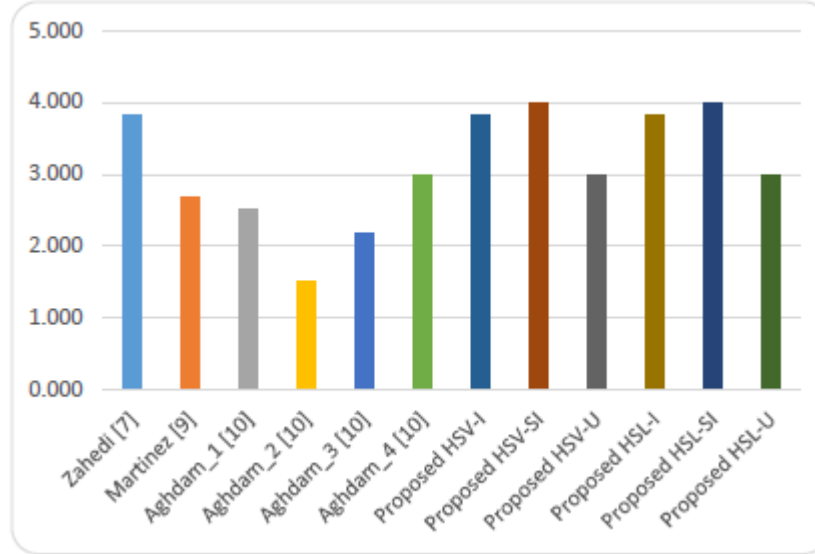

Figure 4. MOS for methods in [7-10] and the proposed color palettes

4.2. Objective Assessment

It's difficult to find the best objective metric to evaluate gray to color images conversion since no reference color image is provided. MSE (8) and PSNR (9) are widely known objective quality assessment methods for image enhancement. Since they measure the difference between two images in the same color space, it makes no meaning to get the MSE between a gray image and a colored one. Some works consider the MSE as an objective assessment method to their colorization methods by either getting the MSE between the original color image and the recolored one or to convert the gray image into RGB image with equal R, G and B values and calculate the difference between the gray RGB image and the colored one. In the latter case, it seems the higher the MSE, the higher the distance between color and gray values, the best the colorization result is.

$$MSE = \frac{1}{3MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[G(i,j) - Cl(i,j)]^2 \qquad (8)$$

$$PSNR = 10\ log\left(\frac{255^2}{MSE}\right) \qquad (9)$$

, where G is the gray image with 3 channels; R, G and B, and Cl is the colored image in RGB space.

Normalized Color Difference (NCD) [3] [12] is another objective measure was used by some researchers. NCD represents the distances between colors in a given color space (Usually Lab color space). The larger the NCD, the worse the image quality is. The NCD indicator is calculated using the following formula:

$$NCD = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\sum_{q \in [L,a,b]} [G_q(i,j) - Cl_q(i,j)]^2}}{\sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\sum_{q \in [L,a,b]} Cl_q(i,j)^2}} \qquad (10)$$

, were G_q and Cl_q are the gray and the colored images with q channel (in Lab space).

Structure Similarity Metric (SSIM) [13, 14] is another objective measure that was proposed based on the human visual system. SSIM reflects how the colorization process affects the structure of the image. Popowicz [15] improved the SSIM by adding a color comparison to the criteria of the grayscale SSIM. Since the SSIM is defined only for grayscale images, it can be adapted for color image colorization by calculating the SSIM for every single color channel independently, then calculating the mean. When taking into consideration decorrelated color spaces, where the channels are orthogonal, we may assess the quality with the root of the sum of squared SSIM results obtained for each channel. The detailed Mean SSIM (MSSIM) could be found in [15].

In this work, MSE, PSNR, NCD, and SSIM measures have been calculated for works in [7-10] as well as the proposed method. Table 1 presents the objectives measures calculated for the proposed palette as well as the methods in [7-10]. As discussed before, MSE and PSNR give different meaning when it comes to colorization. As it is extremely sensitive to the offsets in color or luminance channels. It is possible that, although the visual impression of the image does not change, the PSNR value may be much lower, indicating the poor quality. From the table, it seems the proposed palettes have high MSE and low PSNR. Since NCD is the most suitable measure for colorization procedures assessment [15] it is considered for assessing the 12 methods. The lower the NCD, the better the image quality. Since our proposed system keeps the luminance channel untouched, it's expected to have high MSSIM index. As the MSSIM could be presented as a grayscale image, Figure 5 presents the MSSIM for the Brain MRI image from our test set (Figure 3).

5. CONCLUSION

In this paper, we propose HSV/HSL pseudo-coloring schema for medical images. We have proposed 6 strategies based on the basic proposed structure. The proposed strategies vary in colors range (from red to blue and magenta or vice versa). Using HSV/HSL models enable giving rainbow colors to the gray shades either in the same order or with an inverse order. We recommend using the same gray image as Intensity for keeping the same structure of the image as well as the original intensity information. The recommended binary Saturation channel gives clear pure colors to the captured organs while neglecting the black background here what enhances the visual appeal of the images. Also, it increases the color difference between the original grayscale image (where saturation is set to 0) and the colored image (where the saturation is set to 1). For Hue component generation, three strategies have been suggested; Equal to Intensity (EI), Complement of Intensity (CI) and Stretched Inverted Intensity (SI). Hue contrast stretching has been recommended for giving more colors to a smaller range of gray shades. Subjective and objective testing has been performed showing that the proposed system has high

MOS and SSIM, and low NCD. We can conclude that using HSV/HSB color models in medical images is a good choice subjectively and objectively.

Table. 1. Objective measures for literature palettes [7-10] and the proposed palettes

	Color Space	MSE	PSNR	NCD	SSIM
Martinez [7]	RGB	1.19E+04	16.9628	0.5497	0.7589
Zahedi [9]	RGB	5.09E+03	25.4766	0.4488	0.7874
Aghdam [10]	HSV_1	6.90E+03	22.4306	0.4803	0.8195
	HSV_2	5.30E+03	25.0627	0.4303	0.8502
Aghdam [10]	Lab_1	4.62E+03	26.4341	0.3713	0.8562
	Lab_2	5.99E+03	23.8435	0.3854	0.9834
Proposed	HSV-U	1.06E+04	18.178	0.2933	0.9721
	HSV-SI	1.05E+04	18.2176	0.297	0.9454
	HSV-I	1.06E+04	18.178	0.3366	0.9721
	HSL-U	8.88E+03	19.9045	0.3302	0.9186
	HSL-SI	8.86E+03	19.9339	0.3247	0.8883
	HSL-I	8.88E+03	19.9045	0.3907	0.9186

a)   Martinez [7]   b)   Zahedi [9]   c)   Aghdam_1 [10]   d)   Aghdam_2 [10]   e)   Aghdam_3 [10]   f)   Aghdam_4 [10]

g)   Proposed HSV_U   h)   Proposed HSV_I   i)   Proposed HSV_SI   j)   Proposed HSL_U   k)   Proposed HSL_I   l)   Proposed HSL_SI
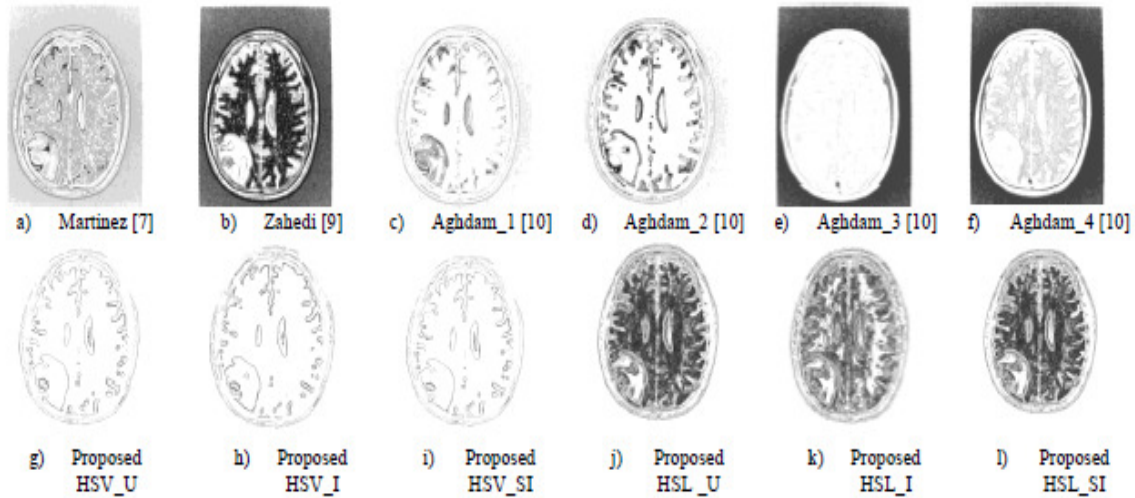
Figure 5. (a-f) MSSIM for Color Palettes of [7-10] methods and (g-l) MSSIM for the proposed color palettes.

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