Novel Compression System for Hue-Saturation and Intensity Color Space

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Abstract: *Common compression systems treat color image channels similarly. Nonlinear color models like Hue-Saturation-Value/ Brightness/ Luminance/ Intensity (HSV/ HSB/ HSL/ HSI) have special features for each channel. In this paper a new hybrid compression system is proposed for encoding color images in HSI color model. The proposed encoding system deals with each channel with a suitable compression technique to obtain encoded images with less size and high decoding quality than the traditional encoding methods. There are three encoding techniques will be mixed in the proposed system; object compression technique for the hue channel, Luma (Y) Intensity (I) Difference (D) for saturation, and the standard JPEG2000 encoding technique for the intensity channel. The proposed system results demonstrate the proposed architecture and give considerable compression ratio with good decoding quality.*

Keywords: *Hue, saturation, intensity, encoding, compression*.

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1. Introduction

Most common image encoding techniques like JPEG, JPEG2000, EZW, and more, deal with the image channels (usually YCbCr channels) similarly. A color model like Red, Green, Blue (RGB), has a linear relation between its three channels, so it's normal to encode the three channels in the same way. But with a nonlinear color model like HSI family or YCbCr, it's better to deal with each channel separately, which means using different compression quality or even different compression technique.

Since there is no famous encoding technique based on HSV or HSI color model. In this paper a new encoding system for images in HSI space is proposed. HSI color model is selected due to its compatibility with human intuition [10], and its unrelated chrominance channels. The main objective of this paper is to prove the ability of using HSI color model for encoding with high compression ratio. Another objective is to propose a new compression system that keeps the quality of colors even with high compressed gray channel.

This paper is organized as follows: Section 2 presents the related works. The proposed system is presented in section 3 in detail. Results are presented and discussed in section 4. Finally, the conclusion of the research is presented in sections 5.

2. Related Works

As a brief description for HSI model features, Figure 1 shows the double cone of HSI model. The hue channel refers to the color ranges as we can name (Red, Green, Yellow…etc.,). From Table 1 and Table 2, the range of hue values changes from 0^o (red) to 360^o (red) passing throw rainbow colors. Saturation value affects the purity of the colors and it differs from gray (0 value) to full saturated/pure color (1 value). Finally, intensity means the amount of light in the color. So, it differs from black to white passing throw the light value and the dark value of the color.

HSI family (HSV/HSB, HSI and HSL) are not supported by common image coding standards like JPEG and JPEG2000 [6]. The reason is like in RGB and CMY color models, HSI spreads its useful visual image information evenly across each of their three color components, making the selective discarding of information very difficult. All three color components would need to be encoded at the highest quality, resulting in a poorer compression ratio [9].

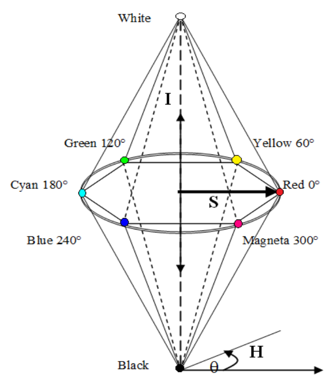


Figure 1. A double cone of HSI color model.

Table 1. Hue and intensity degradations.

Change in I (H=0 and S =1)	Change in H (I=1 and S =1)

Table 2. Saturation degradation.

I-Value	Saturation Changes H=0
1	
0.5	
0.25	

3. HSI Proposed Encoding System

Figure 2 shows the proposed system block diagram. There are three basic encoding techniques will be used; Object Compression encoder (OCP) [7, 8], JPEG2000, and a proposed encoding method based on the Luma (Y) Intensity (I) Difference (D) (YID), for encoding H, I, and S respectively. Detailed description for these algorithms will be presented in next subsections.

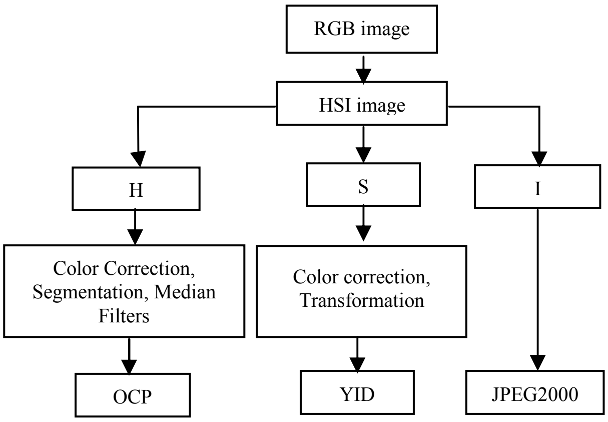


Figure 2. The proposed system blocks.

3.1. Hue Proposed Encoding System

The hue bar shown in Table 1 has 256 integer values (0^o-360^o in the model). Most images have limited number of near hue values which can be represented by less number of values without image distortion. Quantization or color sampling is usually used to minimize the bit per pixel needed to encode H values like in [4, 15].

A lossless object encoding technique will be used to encode H channel in the proposed system. Object encoding techniques depends on extracting the image objects and encode it. The used algorithm is the technique proposed by [7, 8]. It's dedicated to encode images with solid color objects like cartoon images. So, *H* channel should be preprocessed to have more clear objects.

According to the process of converting RGB to HSI space [3, 10], hue values may have values that don't reflect the actual value of the color in RGB image because of saturation or intensity channels effect. To clarify the idea, a simple picture 'color shapes' of size 921KB is shown in Figure 3. The figure shows a color image and its *H*, *S*, and *I* channels shown in Figure 4. As shown in the figure. The big gray area in hue image should appear green in the RGB image, but it's not because S has zero value in this area.

Due to this notes, enhancement stages should precede the compression stage. These enhancements are color correction, segmentation, and median filtering.

Figure 3. Original image 'color shape' 640×480 px.

a) Hue channel. b) Saturation channel. c) Intensity channel.

Figure 4. HSI channels.

3.1.1. Color Correction Stage

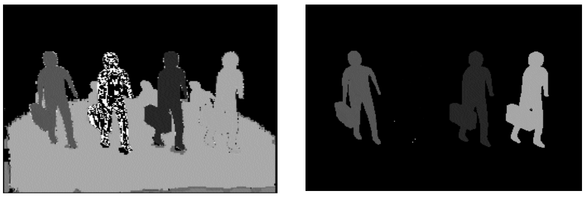
In this paper, a new color correction methodology based on the linguistic color definitions is proposed. The idea based on correcting both hue and saturation channels according to the colors appear in the RGB image without any change in their R, G and B values. The correction procedure is needed to minimize the number of objects in *H* channel to be processed faster and more efficient with OCP method. There are four colors of interest; black, white, gray and red. According to the features of HSI model, the following relations are derived:

- Any gray color has S=0, regardless of H value.
- Black colors has I=0, regardless what H and S values.
- White colors, $I=1$, and S=0, regardless of H value.
- Both Hue bar limits (0, 1) are red.

For a very small accuracy threshold value (ε), the correction procedure in order will be as follows:

- {∀ Black pixel: $I < \varepsilon$, let $S=0 \wedge H=0$}.
- {∀ White pixel: $I > 1- \varepsilon$, let $S=0 \wedge H=0$}.
- {∀ Gray pixel: $S< \varepsilon$, let $S=0 \wedge H=0$}.
- {∀ Red pixel: $H< \varepsilon \wedge H>1-\varepsilon$, let $H=0$}.

where, ∀ means 'For each value of' and $\wedge$ is a logical 'And'. By these correction steps, it's guaranteed to have correct color meaning, and large zero object instead of different non affecting small object values, what will enhance the result of using OCP algorithm. Figure 5 shows the original and the corrected *H* channel after correcting 438275 pixels. The correction leads to merge black, white, and red pixels to one hue value=0, what eliminates the number of objects (wrong objects) in *H* channel. In this paper, ε is set to 0.05.



a) Original hue. b) After correction.

Figure 5. Hue channel before and after correction.

3.1.2. Segmentation Stage

K-means clustering technique is used for segmentation purpose. For computational time acceleration, the algorithm proposed in [2] is used. Figure 6 and Figure 7, show the segmented 'color shapes' image with number of clusters K=4. The K value is the quality parameter of hue encoding stage (Q_H).

Figure 6. Segmented hue image.

Figure 7. Segmentation results (4 objects).

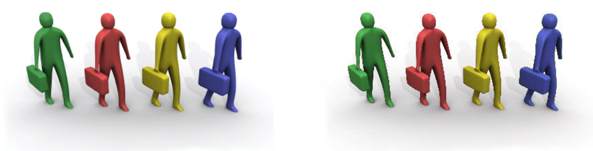
Median filter can be used before compression to eliminate noise pixels. Figure 8 shows the color image with using the segmented *H* instead of the original one. The corrected and segmented *H* channel has no noticeable effect on the final RGB image as seen.

Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) quality measures are used to evaluate the system results. The PSNR and MSE are common image quality metrics calculated using equations 1 and 2 [11]. The MSE and PSNR calculated in this paper measured on the three channels of YCbCr version of the image and the average is considered.

$$PSNR = 10.\log_{10}\left(\frac{255^2}{MSE}\right) \quad (1)$$

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[X(i,j) - Y(i,j)\right]^2 \quad (2)$$

For evaluating the preprocessing stages, first *X* is set to the original image and *Y* is set to the corrected image. The correction evaluation measures are *PSNR=48.8687* and *MSE=0.58956*. For evaluating the segmentation stage, *X* is set to the image with corrected hue and *Y* is set to the image with segmented Hue. The segmentation quality measures are *PSNR=54.5431* and *MSE=0.18115*. The values imply a very good quality for both the corrected and segmented images.



a) Original hue. b) Segmented hue.

Figure 8. Comparison between using the original hue and the segmented hue.

3.1.3. Object Compression Stage

The OCP technique proposed by [7, 8] is based on tracking the objects chain code and then simplify this code. The final encoded data is the minimum pixels needed to regenerate the chain code and the color of each object. The OCP system diagram is shown in Figure 9. It consists of the following basic blocks:

1. *Image Preparation:* Converts the image into 2D matrix, which consists of the pixels values (colors).
2. *Object Extraction:* Applies the minimum number of pixels *MNP* method which extracts the pixels of the current object using chain code.
3. *Object Minimization:* Removes the repeated pixels of the chain codes in horizontal, vertical and diagonal edges respectively, and then removes the intersection pixels between vertical and horizontal edges, and between horizontal and diagonal edges.
4. *Vectorization:* The encoder arranges the rest bounding pixels according to the arrangement that was recorded in object extraction phase giving *W* code for each pixel.
5. *Differential Encoding:* Reduces the number of bits that are required to encode the *W* code.
6. *Huffman Encoding:* To compress the results without any loss.
7. *Frame Building:* To generate the structure that defines the format of total fields in output bit-stream frame.

The OCP system is a very powerful encoding system for cartoon images, but it doesn't work professionally with natural images. The author tried to use the system with bit-plane encoding but the results didn't match the requirements. With the proposed system, OCP algorithm can be used to encode natural images by applying the algorithm on the segmented *H* channel.

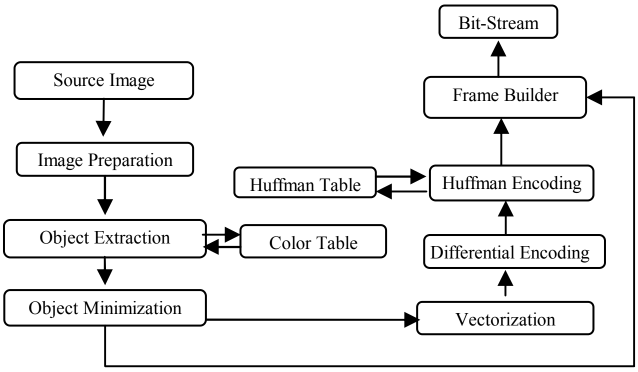


Figure 9. OCP algorithm.

Figure 10 shows the obtained boundary pixels after using OCP. The segmented *H* channel of figure 5 was encoded to reach 2.68KB, with Compression Ratio (CR) equals 0.0176. The CR measured in this paper is calculated by dividing the size of the encoded image by the size of the original image.

Figure 10. Object compression results.

3.2. Saturation Proposed Encoding Algorithm

In this stage, a new encoding technique for *S* channel is proposed. The technique is based on YID. Saturation channel is a noisy channel that has no from or relation between its values and both the hue and intensity values of the image. According to this notes, *S* channel frequency space (e.g., DCT) has a lot of high frequencies which leads to bad compression ratio with the common compression techniques.

The proposed algorithm is based on transforming *S* values (0:1) to another narrower space to be encoded efficiently by DCT. The proposed transformation relays on the equations of RGB/Gray conversion [3, 10]. There are two standard equations to convert from RGB to gray.

$$I = 1/3\ (R+G+B) \tag{3}$$

$$Y = 0.299\ R + 0.587\ G + 0.114\ B \tag{4}$$

where, *I* is the image intensity, and *Y* (Luma) is the weighted average of gamma-corrected *R*, *G*, and *B* (used by NTCS for color television broadcast). *I* is used in HSI color model to represent the luminance component while *Y* is used in YCbCr model. Consider the equations of converting HSI to RGB [3], there are three sectors of *H*:

1. *RG sector:* ($0^{o} \leq H \leq 120^{o}$)

$$\begin{aligned} &B = I(1\text{-}S) \\ &R = I(1+SA) \qquad \text{where} \\ &G = 3I-(R+B) \qquad A = cos(H)/cos(60\text{-}H) \end{aligned} \tag{5}$$

2. *GB sector:* ($120^{o} < H \leq 240^{o}$)

$$\begin{aligned} &R = I(1\text{-}S) \qquad \text{where} \\ &G = I(1+SA) \qquad H = H\text{-}120^{o} \\ &B = 3I-(R+G) \qquad A = cos(H)/cos(60\text{-}H) \end{aligned} \tag{6}$$

3. *BR sector:* ($240^{o} < H \leq 360^{o}$)

$$\begin{aligned} &G = I(1\text{-}S) \qquad \text{where} \\ &B = I(1+SA) \qquad H = H\text{-}240^{o} \\ &R = 3I-(G+B) \qquad A = cos(H)/cos(60\text{-}H) \end{aligned} \tag{7}$$

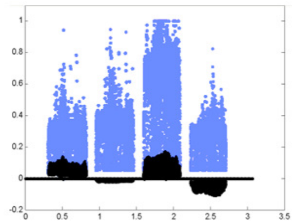
From the equations 4, 5, 6, and 7, *Y* has 3 equations:

$$\begin{aligned} &RG\text{: } Y = I + (0.473\ I - 0.288\ IA)\ S \\ &GB\text{: } Y = I + (0.473\ IA - 0.185\ I)\ S \\ &BR\text{: } Y = I + (-0.185\ IA - 0.288\ I)\ S \end{aligned} \tag{8}$$

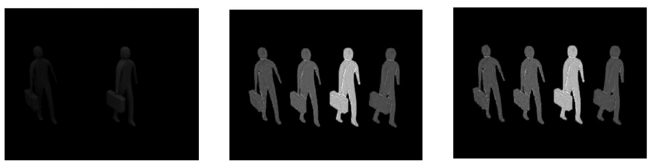
Let *YID* = *Y*- *I* is the difference between Luma (*Y*) and Intensity (*I*). *S* can be computed for the three sectors using the following equations:

$$\begin{aligned} &S_{RG} = YID\ /\ (-0.288\ IA + 0.473\ I) \\ &S_{GB} = YID\ /\ (0.473\ IA - 0.185\ I) \\ &S_{BR} = YID\ /\ (-0.185\ IA - 0.288\ I) \end{aligned} \tag{9}$$

where, S_{RG} is the saturation for RG sector and so, are S_{GB} and S_{BR} for GB and BR sectors respectively. Figure 11 presents the relation between *S* and YID values where x-axe indicates the pixel indexes and *y*-axe indicates to the value of pixel saturation (blue) or YID (black). Finally, *S* can be recalculated at the decoder side using equation 9.



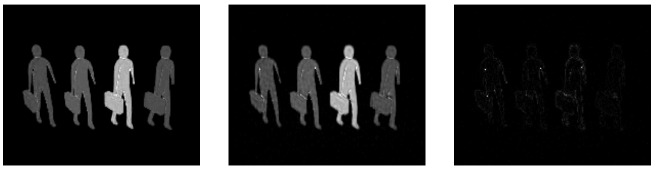
a) S(blue) vs YID(black).



b) YID coefficients. c) Original *S*. d) The estimated *S*.

Figure 11. The relation between the original *S* and the estimated *S* using YID values.

It's found that the ranges of *YID* are less than image saturation by more than 90% and has very low contrasted values so, it's better to process *YID* rather than *S*. For compression purpose, Discrete Cosine Transformation (DCT) is performed to YID image. Since the values of YID are very close to each other, high frequency values in the DCT image are very few. A compression is applied on the *YID* by selecting only the coefficients higher than some threshold which indicates the compression quality (Q_S). In this example Q_S=0.01 is the selected threshold, and the obtained compression ratio is 0.0116. The estimated *S* is shown in Figure 12.



a) Original *S*. b) Decoded *S*. c) Difference.

Figure 12. Difference between the original and the estimated S.

3.3. Intensity Encoding Algorithm

The standard JPEG2000 encoder presented in [3] is used for encoding *I* channel. JPEG2000 was proposed by Joint Photographic Experts Group committee in 2000 [1]. The coding algorithm is based on Discrete Wavelet Transform (DWT) to an arbitrary depth, in contrast to JPEG which uses an 8×8 block-size discrete cosine transform. The JPEG2000 standard supports lossy and lossless compression of greyscale or color imagery. In addition to this basic compression functionality, numerous other features are provided, including:

1. Progressive recovery of an image by fidelity or resolution.
2. Region of interest coding, whereby different parts of an image can be coded with differing fidelity.
3. Random access to particular regions of an image without needing to decode the entire code stream.
4. A flexible file format with provisions for specifying opacity information and image sequences.
5. Good error resilience. Due to its excellent coding performance and many attractive features, JPEG2000 has a very large potential application base [1].

First, the image is split into rectangular regions -called tiles, of the image that are transformed and encoded separately. These tiles are then wavelet transformed. In JPEG2000, multiple stages of the DWT are performed. The coefficients are scalar-quantized to reduce the number of bits to represent them. Before coding is performed, the subbands of each tile are further partitioned into relatively small code-blocks to permit a flexible bit stream organization. After a subband has been partitioned into code blocks, each of the code blocks is independently coded using bit-plane coder.

4. Results and Discussions

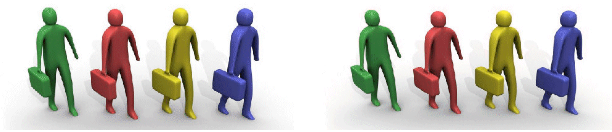
Since the proposed system considers chromatic compression, common quality metrics like *MSE* and *PSNR* are not sufficient. Another quality metric called "Colorfulness" is used for quality assessment process [14]. Image colorfulness measures the amount of the color in an image. The colorfulness value (*C*) for an image is defined as:

$$C = \sqrt{\sigma_\alpha^2 + \sigma_\beta^2} + 0.3\sqrt{\mu_\alpha^2 + \mu_\beta^2} \quad \text{where} \quad a = R - G, \quad \beta = \left(\left(R - G/2\right)\right) - B \tag{10}$$

where, μ and σ are the mean and standard deviations of the pixel cloud along two axes α and β in a simple opponent space. For comparing the colorfulness quality between an image (*X*) and the decoded image (*Y*), the Colorfulness Metric (CM) is defined by:

$$CM(X, Y) = |C_X - C_Y| \tag{11}$$

where the smaller the value of *CM* the closer the decoded image to the original one. After encoding the intensity channel (*I*) of the above example by JPEG2000 with quality Q_I=8, the final decoded color image is shown in Figure 13. The quality assessment measures for this example are *PSNR=39.08*, *MSE=8.024*, *CM=1*, and *CR=0.055*.



a) Original image. b) Decoded image.

Figure 13. The original vs. the decoded images.

A comparison between the proposed HSI encoding system and JPEG2000 for both YCbCr and HSI color models was performed. The comparison was based on using the same JPEG2000 compression quality (Q_I) for each of the images to keep the same structure similarity map. Figure 14 shows the compression results of JPEG2000 using YCbCr (*a*) and HSI (*b*), and the results of the proposed system (*c*). A zoomed part is shown in Figure 14-d. The structure map of the images is shown in Figure 14-e. Subjectively, it appears that, with keeping the same gray channel structure, the proposed system can keep the quality of colors, while the colors in JPEG2000 are distorted with both HSI and YCbCr models.

Table 3 presents the comparison measures. The values imply the efficiency of the proposed system. The proposed system has the least MSE and CM, while it has the most PSNR value. Although, the compression ratio obtained from the system is more than JPEG2000 with YCbCr, it's less than JPEG2000 with the same color space HSI.

Table 3. JPEG2000 vs. proposed system.

	YCbCr_JPEG2000	HSI_JPEG2000	Proposed
MSE	55.13	44.9	39.9
PSNR	30.7	31.604	35.12
CM	1.304	0.6395	0.372
CR	0.003	0.008	0.004

a) JPEG2000 using YCbCr color model.

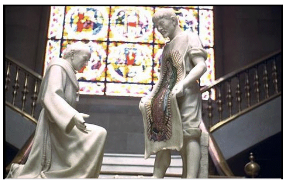
b) JPEG2000 using HSI color model.

c) Proposed method.

d) Magnified parts from figure (a), (b) and (c).

Figure 14. Comparison between the proposed system and JPEG2000 encoding method.

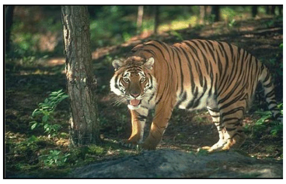
More images from Berkeley Database [5] were used for testing; original images size is 452KB. The system quality parameters used in these examples are (Q_H=7, Q_S=0.01 and Q_I=8). Figures 15 and 16 present the original and the decoded images. The quality measures PSNR, MSE, CM and CR (displayed under the figures) imply a good decoding quality and satisfiable compression ratio. Reader can compare the results of the proposed YID method with our previously proposed method Minimum Color Difference (MCD) published in [12, 13].



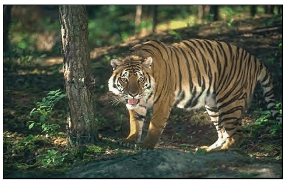
a) Original.

b) Decoded.

Figure 15. System results (PSNR=39.1796, MSE=6.5, CM=0.56, CR=0.13).



a) Original.



b) Decoded.

Figure 16. System results (PSNR=35.63, MSE=13.9, CM=0.8, CR=0.131).

5. Conclusions

In this paper, a new color image compression system dedicated to HSI color space was proposed. The proposed algorithm was based on encoding each channel using a suitable encoding algorithm. First, hue channel was encoded using an object compression algorithm after being corrected by a proposed correction algorithm. Then, saturation channel was transformed using a proposed transformation method based on YID and encoded using DCT. Finally, intensity channel was encoded using standard JPEG2000 algorithm. From system results and comparisons with JPEG2000 encoder, the proposed system tends to be very lossy compression technique with subjective quality preservation even with highly compressed gray channel. By other words 'a perceptually lossless compression method [10].

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