HUE-BASED QUATERNIONIC CRITERION FOR FOCUSED-COLOR EXTRACTION

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ABSTRACT

In this paper, a method of specific colored area extraction into a color image is presented. Usual color segmentation or edge detection operators perform a global processing on the image. Thus, every area into an image is detected. The whole image is subdivided into several region by labeled pixels, or boundaries in case of an edge detection. Our purpose is to extract only specific areas into an image sharing a specific color attribute, hence sharing a common color based on a specific hue. The quaternionic geometrical transformation into RGB color space is used. A specific hue axis is defined. From this axis, a criterion defines a color subspace into an RGB color space using the quaternionic HSI interpretation of RGB vectors.

Index Terms—Color images, Edge detection, Color Extraction, Color subspace, Quaternions.

1. INTRODUCTION

A very large set of approaches, like [1, 2, 3], have been proposed to perform edge color detection in the color images. The edge detection is an important step to perform image segmentation. However, these methods perform a global detection and provide a full image subdivision. The aim of the presented method is to extract only specific areas into an image. These regions share a common color attribute based on the hue. Some filters have been proposed to extract specific color pixels into images using quaternions [5, 6, 7]. However these methods are only using a direct distance between color relative to one or two color axis. The intensity and the relative saturation have to be taken into account to perform a relevant extraction. The aim of this work is to isolate particular edges or a pixel class sharing a same colorimetric attribute. A specific group of areas with a common attribute are extracted by defining a particular subspace into the color space. The hue, the intensity and the saturation are taken into account. The quaternions are used in the presented method to extract colored edges or pixels into the images. A new quaternion-based criterion is proposed for a detection of specific color regions. The proposed criterion is based on the quaternionic HSI interpretation of RGB vectors. Further work using the presented method will aim to perform a tracking of target defined by their colorimetric attribute(s) into videos. This paper is organized as follow : First, quaternions are briefly introduced and the HSI representation of color with quaternions is presented. Then, the quaternionic edge detector [4] and the color gradient described in [8] are presented. Two dual approaches are presented. The first method uses directly the subspace definition to process a classification of the color vectors (the pixels). A second approach, based on the edge detection, uses a comparison of the adjacent pixels of the detected edge and select appropriate edges in accordance to the color criterion. Finally, some results obtained with these methods are discussed.

2. QUATERNIONS

2.1. Definitions

The quaternions (or hypercomplex numbers) are an extension of complex to four dimensions. Proposed by Hamilton in 1843 [9], quaternions have been more recently used with color spaces since several years. They can be considered as complex numbers with a real part and three imaginary parts. A quaternion \( q \in \mathbb{H} \) is usually represented as, \( q = w + xi + yj + zk \), where \( w, x, y \), and \( z \) are real and \( i, j, k \) are the complex operators which are following these properties \( i^2 = j^2 = k^2 = ijk = -1 \) and \( ij = k, \ jk = i, ki = j, ji = -k, kj = -i, ik = -j \). Given a quaternion \( q \), its conjugate is \( \bar{q} = w - xi - yj - zk \) and its modulus is \( |q| = \sqrt{w^2 + x^2 + y^2 + z^2} \). A pure quaternion is a quaternion with a zero real part and a unit quaternion has a unit modulus equal to 1. Pure quaternion space is usually denoted \( \mathbb{P} \) and unit quaternion space is usually denoted by \( \mathbb{S} \). A quaternion can be splitted into a scalar part \( S[q] \) and a vector part \( V[q] \). And thus, \( q = S[q] + V[q] \) where \( V[q] = xi + yj + zk \). Note that the quaternionic product is anti-commutative.

If we consider pure quaternions representing three-dimensional vector of \( \mathbb{R}^3 \), this vector representation induces an interesting property of the quaternionic product. The quaternion \( q = q_1q_2 \) can be written as, with \( V_1 \) and \( V_2 \), the respective vector part of \( q_1 \in \mathbb{P} \) and \( q_2 \in \mathbb{P} \):

\[
q = q_1q_2 = -V_1V_2 + V_1 \wedge V_2
\]

Using this property, reflexion, projection, rejection and rotation have been expressed in quaternion space, using only quaternions additions and multiplications as described by Sangwine in [5]. All these operations allow to manipulate the colors associated vectors in a given colorimetric space, most of the case RGB space. With \( q \in \mathbb{P} \), the axis reflection of \( q \) with an axis \( \mu \in \mathbb{S} \cup \mathbb{P} \) is given by \( q_{\perp \mu} = -\mu q \mu \), the projection of \( q \) on axis by \( q_{\parallel} = \frac{1}{2}(q + \mu q \mu) \) and the rejection by \( q_{\perp} = \frac{1}{2}(q - \mu q \mu) \).

2.2. Quaternions and color images

If we consider RGB space, each pixel of an image \( I \) of size \( N \times M \) can be described by the following pure quaternion, with \( n \in [1..N] \) and \( m \in [1..M] \):

\[
I(n, m) = 0 + r(n, m)i + g(n, m)j + b(n, m)k
\]

2.2.1. HSI representation of color with quaternions

For a given color quaternion \( q \in \mathbb{P} \) representing a vector in RGB space, the three components, hue, saturation and intensity of HSI
color space can be expressed using quaternionic operations. For a vector \( q \), \( I \) and \( S \) are obtained by the projection and the rejection of the vector relatively to the gray axis and the hue can be defined by the angle formed by the rejection vector and a reference axis \( v \) in the plane perpendicular to \( \mu \) defined by the two vectors \([10]\). Thus:

\[
\begin{align*}
H &= \tan^{-1} \frac{q - \mu q \mu}{q - \mu q \mu}, \\
S &= \frac{1}{2} (q + \mu q \mu), \\
I &= \frac{1}{2} (q - \mu q \mu)
\end{align*}
\]  

Fig. 1. Hue, saturation and intensity with gray reference axis \( \mu \) and hue reference axis \( v \)

### 2.2.2. Quaternionic color edge detector

This edge detector, proposed by Sangwine \([4]\), is based on the quaternionic convolution in a color image:

\[
\hat{q}(s,t) = \sum_{\tau_1=m-n}^{m} \sum_{\tau_2=m-n}^{m} h_1(\tau_1, \tau_2)q(s-\tau_1, t-\tau_2)h_2(\tau_1, \tau_2)
\]  

where \( h_1 \) and \( h_2 \) are two conjugate filters. From this convolution operator, a color edge detector can be defined with two filters which produce a rotation of \( \pi \) around the gray axis, hence a reflection, of the pixels and compare them to the neighbourhood.

\[
h_1 = \begin{pmatrix} 1 & 1 & 1 \\ Q & Q & Q \end{pmatrix}, \quad h_2 = \begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \end{pmatrix}
\]  

where \( Q = e^{\pi i} \) and \( \mu = \frac{i+j+k}{\sqrt{3}} \) the gray axis. The result of this filtering is an image with a strong grayscale dominance corresponding to homogeneous regions of the considered image. However, when a pixel is in opposition with its neighbours in term of color, the resulting pixel is a color vector, and thus detected edge is colored.

Assuming edges are colored and homogeneous regions are grayed in the filtered image, a sample way to extract the edges is to process a thresholding on the saturation of the filtered pixels using the saturation definition given above, equivalent to a distance \( d \) of the filtered vector \( \hat{q} \) to the gray axis \( \mu_{\text{gray}} \).

\[
d = \left| \frac{1}{2} (\hat{q} + \mu_{\text{gray}} \hat{q}_{\text{gray}}) \right|
\]  

This operation, defined by Denis \([8]\), allows to determine a color gradient by filtering into different directions: horizontal, vertical and diagonal. The maximum of the saturation values obtained are selected to define the gradient at the pixel position. The thresholding on these values allows to calculate an edge map of the image. However, in this method, authors only take into account the presence of color of the edges without dealing with their meaning. Our purpose is to show that this edge color can give more information on the regions and/or frontiers color properties.

The Fig. 2.(d) shows the hue of the edge extracted by the detector. This is clear that all edges do not represent the same color transitions between areas. One of our purpose is to extract only a specific subset of edges associated to some specific color transitions by taking into account the content of the areas bounded by the edges.

### 3. HUE-BASED QUATERNIONIC COLOR SUBSPACE DEFINITION

In this section a criterion allowing to define color space subsets is presented. Given a color \( c \), an axis can be defined to compute an extraction of some specific edges from the detected ones. The value of the edge pixels and their neighborhood in the direction of the gradient are taken into account to extract specific edges and to isolate specific colored regions. Thus, colorimetric information is included in the detection and extends the accuracy of the detection. So, considering a given color \( c = (r, g, b) \), an axis \( \mu_{\text{color}} \) can be defined by:

\[
\mu_{\text{color}} = \left( \frac{r_c}{\sqrt{r_c^2 + g_c^2 + b_c^2}}, \frac{g_c}{\sqrt{r_c^2 + g_c^2 + b_c^2}}, \frac{b_c}{\sqrt{r_c^2 + g_c^2 + b_c^2}} \right)
\]

Let \( \Omega \) be the vector field representing the set of all the color vectors of the image. A subset of vectors sharing the same color as an axis \( \mu \) can be defined. Let \( H(\mu) \) be this subset. The distance of a vector \( q \) from an axis \( \mu \) is given by \(|q - \mu q \mu| = \frac{1}{2} (q + \mu q \mu)\) as shown in section 2. Another definition of \( H(\mu) \) is the set of all vectors \( q \) like \( q_\perp = 0 \). We need to define a subset of vectors which are close to the axis \( \mu \) but which are not necessarily sharing exactly the same hue and the same saturation, hence being colinear to the axis. The definition of \( H(\mu) \) can be relaxed by including all vectors \( q \) with a distance \( q_\perp \) inferior to a threshold \( \alpha \). Let \( H_\alpha(\mu) \) be this subset defined by:

\[
H_\alpha(\mu) = \{ q \mid |q_\perp| < \alpha \}
\]  

A diagram describing this subset is shown on Fig. 3.(a). The value of \( \alpha \) can be weighted by the intensity ratio in order to avoid wrong detection when the intensity is low and then:

\[
\alpha' = \alpha \times \frac{I}{\sqrt{3}}
\]  

where \( I \) is the intensity of a pixel. Thus, \( \alpha' \) can be used into the subset definition instead of \( \alpha \). Indeed, the color information of vector is not meaningful when \( I \) is low because it corresponds to a low value of saturation. A strong dark red is almost black for example. This subset contains every color having a hue into a range of hue \( h_\alpha \) and a saturation into a range of saturation \( s_\alpha \). The intensity is bounded by two intensities \( I_{\text{max}} \) and \( I_{\text{min}} \) to avoid wrong detection of black and white colors. The Fig. 3.(b-c). shows a representation of the subspace into the HSI cone.

At this step, a classification of every pixels can be computed on an image by separating pixel vectors \( q \in H_\alpha(\mu) \) having the appropriate color and each other pixel vectors \( q \in \Omega - H_\alpha(\mu) \) of the image. This area extraction is shown on Fig. 4. on the image Pills.
An example of area extraction has been performed with a light yellow (0.80, 0.64, 0.31) and a purplish red (0.8, 0.02, 0.12). The value of \( \alpha \) is 0.2 and gives good detection results. The respective yellow and red part of the pills are well extracted. For example, on the red extraction, the purple letters inside the red section of the pills are not selected.

The same criterion can be applied to a specific edge detection instead of a region-based extraction. Using the above presented subspace definition, extraction of edges can be performed when they correspond to a transition from one given color range to any other different color range. In other words, the aim is to extract the edges associated to a transition between one color \( q_1 \in H_\alpha(\mu) \) and every other colors \( q_2 \in \Omega - H_\alpha(\mu) \). This selection of edges can be done by comparing adjacent pixels to the edge ones.

The Fig. 5. illustrates the edge selection between three regions. Only edges between regions belonging to \( H_\alpha(\mu) \) and other regions are selected. Given an edge pixel and a gradient direction, adjacent pixels \( q_1 \) and \( q_2 \) are considered. Let \( q_1 \rightarrow q_2 \) be the transition between the two colors associated to \( q_1 \) and \( q_2 \). The table 1. summarizes the three possible cases.

\[
\begin{array}{|c|c|}
\hline
\text{Condition} & \text{Transition } q_1 \rightarrow q_2 \\
\hline
|q_1^+| + |q_2^-| \geq \alpha + |q_2^-| & \Omega - H_\alpha(\mu) \rightarrow \Omega - H_\alpha(\mu) \\
|q_1^+| + |q_2^-| < \alpha + |q_2^-| & H_\alpha(\mu) \rightarrow \Omega - H_\alpha(\mu) \\
|q_1^+| + |q_2^-| \leq 2\alpha & H_\alpha(\mu) \rightarrow H_\alpha(\mu) \\
\hline
\end{array}
\]

Table 1. Summary of the transitions \( q_1 \rightarrow q_2 \) groups.

Considering this definition, only the edges of the second group have to be selected to perform the specific detection. The method has been tested on several common test images (Peppers, Lena, Brandyrose, Pills, ...). An example is given in the Fig. 6.(a-d), which illustrates the detection with different colors on Pills image. Colored section of the pills are well bounded in accordance to the selected color. The results obtained on other test images are equivalent. Thus, this detector fulfills our aim of color-selective edge detection.
Fig. 4. Pixel extraction - (a) Original image (b) $\Omega - H_\alpha(yellow)$ (c) $H_\alpha(yellow)$ (d) $\Omega - H_\alpha(red)$ (e) $H_\alpha(red)$

Fig. 5. Edge selection following the criterion: only edges bounding a region of a given color and every regions of any other color except this color are selected.

4. CONCLUSION

In this paper, a study on a specific color extraction using hypercomplex has been presented. A new criterion based on HSI quaternionic interpretation of RGB vectors has been defined. Following this criterion, a color subspace is defined to extract specific color areas into an image. This subspace definition allows to compute two dual operations respectively of color classification and of specific color edge selection. This study optimizes color detection in term of focused-color selection. This work gives promising results and opens ways to color-oriented detection by means of axis linked to specific colors. Further work on a multiple subsets definition will be conducted to compute polychromatic object extraction and target tracking into videos.

5. REFERENCES