A Fuzzy Approach to Dominant Color Description for Image Retrieval

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Abstract

In this paper a fuzzy approach to deal with vagueness in the image color description is presented. The concept of dominant fuzzy color is proposed, using linguistic labels for representing the color information in terms of hue, saturation and intensity. Based on these fuzzy dominant colors, inclusion and resemblance query operators are proposed to perform flexible queries on a database by means of color linguistic labels.

Keywords: Fuzzy color descriptor, image retrieval.

1 Introduction

Nowadays, the amount of visual information available all over the world is growing in an impressive way. This fact has motivated an increment of the research about techniques for storing, indexing and retrieving images on databases [3].

To achieve a good performance in the retrieval process, efficient methods for describing images are needed. The current retrieval systems face this issue by means of features, such as color, texture or shape, which are automatically extracted from images. In this context, dominant colors arise as a powerful tool for describing the representative colors in an image, allowing for efficient indexing of large databases.

Many approaches to dominant color extraction have been proposed in the literature [1, 7, 9], though most of them do not consider the imprecision in the color description. To deal with this problem, some approaches introduce the use of fuzzy logic in the feature representation [4, 8]. These fuzzy approaches allow to perform queries on the basis of linguistic terms, avoiding one of the drawbacks of the classical image retrieval systems, where the queries have to be defined on the basis of images or sketches similar to the one we are searching for.

In this paper, a representation based on dominant colors will be used. To deal with the problem of imprecision, novel definitions of fuzzy color and fuzzy HSI color space will be introduced for describing the dominant colors in terms of linguistic labels. Each label will be related to concepts used by humans in the perception of colors (hue, saturation and intensity), allowing for queries in terms of color components.

The proposed methodology obtains the dominant fuzzy colors from images in two stages: firstly, a set of crisp dominant colors is extracted (section 2); then, each color calculated in the previous stage is employed to obtain the set of dominant fuzzy colors (section 3). In order to perform queries by means of color linguistic labels, inclusion and resemblance query operators are defined (section 4), taking as parameters the fuzzy colors describing the images. Examples of queries are presented in section 5 and, finally, the main conclusions are summarized in section 6.

2 Dominant colors

In this section a methodology to extract dominant crisp colors from images is presented (subsection 2.2) using the HSI color space (subsection 2.1). The notion of fuzzy degree of dominance is finally introduced in subsection 2.3.

2.1 Color space

To process the color information, the HSI colour space will be used. Although the RGB is the most used model to acquire digital images, it is well known that it is not adequate for colour image analysis. Furthermore, the colour components of this space do not have an intuitive interpretation according to the human perception of color. Instead, other colour spaces based on human perception (HSI, HSV or HSL) seem to be a better choice. [1].

In these perceptual spaces, the hue component (H) represents the colour tone (for example, red or blue), saturation (S) is the amount of colour (for example, bright red or pale red) and the third component (called intensity, value or lightness) is the amount of light (it allows to distinguish between a dark colour and a light colour).

2.2 Dominant crisp color extraction

In the literature there are many crisp approaches to dominant color extraction, for example those based on histogram analysis or clustering techniques. In this paper we will perform a clustering approach using the Batchelor&Wilking algorithm [5], where the number of clusters is unknown a priori. This method is initialized with one cluster consisting of all pixels and then an iterative split procedure is performed until a stopping criterion is met. This stopping criterion is based on a parameter $\theta \in [0,1]$ related to the maximum distance to be achieved between points within each cluster (in this paper we have fixed $\theta = 0.3$). To measure the distance between points, the distance between HSI colours proposed in [2] will be used. As a result, we obtain a set of N clusters where the centroid of each cluster, calculated as the mean value, defines a dominant color. In the following, the set of dominant colors will be noted as DCS, with

$$DCS = \{\mathbf{dc}_1, \mathbf{dc}_2, \ldots, \mathbf{dc}_N\} \qquad (1)$$

and $\mathbf{dc}_k = [h_k, s_k, i_k]$ being a dominant crisp color represented in the HSI color space.

2.3 Degree of dominance

Intuitively, a color is dominant to the extent it appears frequently in a given image. It seems natural to model the idea of frequent apparition by means of a fuzzy set over the percentages, i.e., a fuzzy subset of the real interval $[0,1]$. Hence, we define the fuzzy subset *Dominant* of colors as follows:

$$Dom(\mathbf{c}) = \begin{cases} 0 & fr(\mathbf{c}) \leq u_1 \\ \frac{fr(\mathbf{c})-u_1}{u_2-u_1} & u_1 \leq fr(\mathbf{c}) \leq u_2 \\ 1 & fr(\mathbf{c}) \geq u_2 \end{cases} \qquad (2)$$

where $fr(c)$ is the percentage of pixels with color $\mathbf{c}$ in the image under consideration, and u_1 and u_2 are two parameters such that $0 \leq u_1 < u_2 \leq 1$. We have intuitively fixed them to be $u_1 = 0.05$ and $u_2 = 0.2$.

3 Extraction of dominant fuzzy colors

In this section, a set of dominant fuzzy colors is obtained taking as starting point the set of dominant crisp colors extracted in the previous one. Let us remark that the use of fuzzy sets, and the associated linguistic labels, allows to represent the dominant colors in the same way that humans do, that is, using concepts like hue, saturation, and intensity.

3.1 Fuzzy HSI color space

We introduce the following definitions:

Definition 1 *A fuzzy HSI color $\widetilde{C}$ is a linguistic label whose semantics is represented by a fuzzy subset of* $[0, 2\pi] \times [0,1] \times \{0, \ldots, 255\}$.

Definition 2 *A fuzzy HSI color space* $\widetilde{HSI}$ *is a set of fuzzy HSI colors that define a partition of* $[0, 2\pi] \times [0, 1] \times \{0, \ldots, 255\}$.

One very convenient way of defining and representing a fuzzy HSI color space is to employ a fuzzy hue space, a fuzzy saturation space and a fuzzy intensity space, consisting of fuzzy hues, fuzzy saturations and fuzzy intensities, respectively. We introduce these concepts in the following definitions:

Definition 3 *A fuzzy hue (resp. saturation, intensity) is a linguistic label whose semantics is represented by a fuzzy subset of* $[0, 2\pi]$ *(resp.* $[0, 1]$, $\{0, \ldots, 255\}$*).*

Definition 4 *A fuzzy hue (resp. saturation, intensity) space is a set of fuzzy hues (resp. saturations, intensities) that define a partition of* $[0, 2\pi]$ *(resp.* $[0, 1]$, $\{0, \ldots, 255\}$*).*

By using these concepts, a fuzzy HSI color $\widetilde{C}$ can be defined and represented in practice by a triple $[\widetilde{C}_H, \widetilde{C}_S, \widetilde{C}_I]$, where $\widetilde{C}_H$, $\widetilde{C}_S$, and $\widetilde{C}_I$ are a fuzzy hue, a fuzzy saturation and a fuzzy intensity, respectively. In this way, the fuzzy sets representing the fuzzy HSI colors that form a fuzzy HSI color space can be obtained by combining the corresponding fuzzy sets representing fuzzy hues, saturations and intensities in a suitable way. For the sake of simplicity, we shall employ the name of the linguistic label to name also the corresponding fuzzy set.

This procedure has several advantages. First, less linguistic labels have to be defined. Second, we can represent and work with every component of the fuzzy HSI color individually (for example, we could query for colors with red hue). Finally, the linguistic labels associated to fuzzy HSI colors can be obtained by combining the corresponding linguistic labels associated to fuzzy hues, intensities and saturations.

In general, the representation of $\widetilde{C}$ as a fuzzy subset of $[0, 2\pi] \times [0, 1] \times \{0, \ldots, 255\}$ can be obtained as follows:

$$\widetilde{C}(h, s, i) = \min\{\widetilde{C}_H(h), \widetilde{C}_S(s), \widetilde{C}_I(i)\} \quad (3)$$

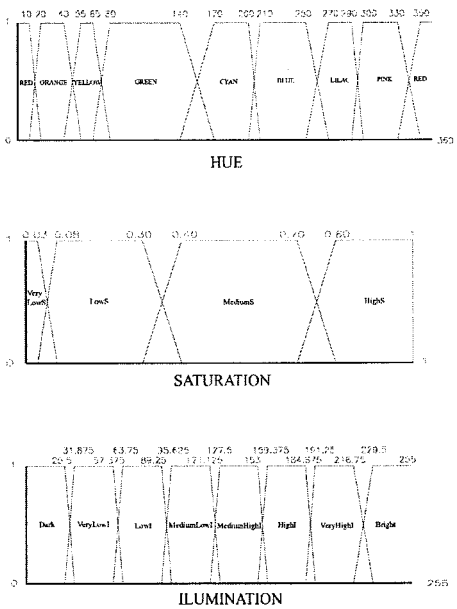

Figure 1: Fuzzy HSI color space

In this work we have employed the fuzzy spaces for hue, saturation and intensity that are shown in figure 1. Trapezoid functions have been used to define the fuzzy sets memberships. Let us remark that the size of the kernels is different in the Hue and Saturation components.

3.2 Dominant fuzzy colors

On the basis of the fuzzy HSI color space defined in the previous section, we introduce the concept of dominant fuzzy color in an image as follows:

Definition 5 *A dominant fuzzy color is fuzzy HSI color that appears frequently in the image.*

As in the case of dominant crisp colors, this definition is imprecise in nature, i.e., "dominant" is an imprecise concept defined on the set of fuzzy colors.

Many approaches are possible to calculate how dominant is a fuzzy color in an image. One possible approach is to calculate the frequency with which each fuzzy color appears

in the image, by using some fuzzy cardinality measure. This will be dealt with in future papers.

One alternative approach we adopt in this paper is to obtain the fuzzy subset of dominant fuzzy colors from the set of crisp dominant colors. We shall consider that a fuzzy color is dominant to the extent that it matches a dominant crisp color.

Since we consider that a fuzzy color is dominant when it is compatible with a dominant crisp color, the degree of dominance of a fuzzy color can be defined as the maximum among the crisp dominant colors of the degree to which the fuzzy color is compatible with a crisp dominant color, and the degree to which that color is dominant. This leads to the following definition:

Definition 6 *Let* $DCS = \{\boldsymbol{dc}_1, \ldots, \boldsymbol{dc}_N\}$ *be the set of dominant crisp colors where* $\boldsymbol{dc}_k = [h_k, s_k, i_k]$. *The fuzzy subset of dominant fuzzy colors for an image will be*

$$\widetilde{DCS} = \bigcup_{k \in \{1,\ldots,N\}} \widetilde{DCS}_k \tag{4}$$

where

$$\widetilde{DCS}_k = \sum_{\widetilde{C} \in \widetilde{HSI}} \left(\widetilde{C}(\boldsymbol{dc}_k) \otimes Dom(\boldsymbol{dc}_k) \right) / \widetilde{C} \tag{5}$$

with $\otimes$ *being a t-norm (we use the minimum in this paper) and where* $\widetilde{C}$ *is a fuzzy color of the fuzzy HSI color space* $\widetilde{HSI}$, $\widetilde{C}(\boldsymbol{dc}_k)$ *is calculated according to equation 3, and the union is performed using the maximum.*

4 Fuzzy operators

The current section describes the operators which have been used to define conditions in image retrieval queries.

4.1 Fuzzy inclusion operator

Given two fuzzy subsets of dominant fuzzy colors, $\widetilde{DCS}^i$ and $\widetilde{DCS}^j$, the operator presented in this section calculates the inclusion degree of $\widetilde{DCS}^i$ in $\widetilde{DCS}^j$. The calculus is done using a modification of the *Resemblance Driven Inclusion Degree* introduced in [6], which computes the inclusion degree of two fuzzy sets whose elements are imprecise.

Definition 7 (Resemblance Driven Inclusion Degree). *Let* A *and* B *be two fuzzy sets defined over a finite reference universe* $\mathscr{U}$, μ_A *and* μ_B *the membership functions of these fuzzy sets,* S *the resemblance relation defined over the elements of* $\mathscr{U}$, $\otimes$ *be a t-norm, and* I *an implication operator. The inclusion degree of* A *in* B *driven by the resemblance relation* S *is calculated as follows:*

$$\Theta_S(B|A) = \min_{x \in \mathscr{U}} \max_{y \in \mathscr{U}} \theta_{A,B,S}(x,y) \tag{6}$$

where

$$\theta_{A,B,S}(x,y) = \otimes(I(\mu_A(x), \mu_B(y)), \mu_S(x,y)) \tag{7}$$

We propose a modification that substitutes the minimum aggregation operator in equation 6 by a weighted mean aggregation operator, whose weight values are the membership degrees in A of the elements of $\mathscr{U}$, divided by the cardinal of A. This modification is made in order to obtain a less extreme resemblance inclusion degree, since it takes into account the importance of each included element. The *Modified Resemblance Inclusion Degree* is defined in equation 8.

$$\Theta_S(B|A) = \sum_{x \in \mathscr{U}} \frac{\mu_A(x)}{|A|} \cdot \max_{y \in \mathscr{U}} \theta_{A,B,S}(x,y) \tag{8}$$

with $|A| = \sum_{x \in \mathscr{U}} \mu_A(x)$. Our implementation uses the minimum as t-norm, and as implication operator the one defined in equation 9.

$$I(x,y) = \begin{cases} 1 & \text{if } x \leq y \\ y/x & \text{otherwise} \end{cases} \tag{9}$$

4.2 Fuzzy resemblance operator

The operator presented in this section calculates the resemblance degree between two fuzzy subsets of dominant fuzzy colors. This resemblance degree is calculated by means of

the *Generalized Resemblance between Fuzzy Sets* proposed in [6], which is based on the concept of double inclusion.

Definition 8 *(Generalized resemblance between fuzzy sets). Let A and B be two fuzzy sets defined over a finite reference universe $\mathscr{U}$, over which a resemblance relation S is defined, and $\otimes$ be a t-norm. The generalized resemblance degree between A and B restricted by $\otimes$ is calculated by means of the following formulation:*

$$\sqsupset_{S,\otimes}(A,B) = \otimes(\Theta_S(B|A), \Theta_S(A|B)) \quad (10)$$

5 Query examples

The described fuzzy operators make the expression of different queries based on the inclusion, or resemblance, of fuzzy sets of dominant colors, possible.

5.1 Dominant color inclusion query

For instance, we would want to obtain from a database the images *including any kind of red hue*, which includes *pale dark red, light bright red*, etc. The previous condition is defined by applying the inclusion operator on the image descriptor and a fuzzy set of dominant colors, which includes only one fuzzy color defined using the linguistic label *red* for the hue component, and the linguistic label *unknown* for the saturation and intensity components (in the case of *unknown* label, that component is not considered in the comparison). The results of this query applied on a database containing about 700 color images, are shown at the top of figure 2 ordered by relevance.

A similar example, using only the intensity component, is shown at the bottom of figure 2. In this case we are interested in dark images and in bright images, independently of the hue or saturation.

Results on a flag database containing 160 images are shown in Figure 3. In this example, the queries performed consider all the color components. On the bottom of Figure 3, the fuzzy colors (linguistic labels) used on the query and a representative crisp color which

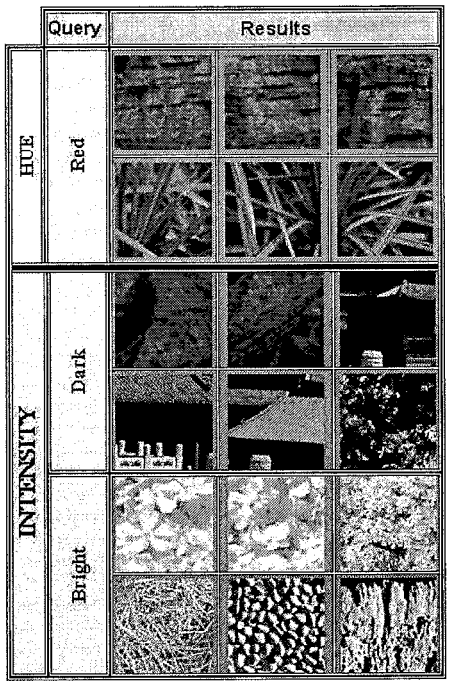

Figure 2: Color inclusion query results using only one component

accomplishes with this fuzzy color are shown. On the top-left, query results corresponding to flag images containing the query color are shown.

5.2 Dominant color resemblance query

Also, we could be interested in getting images with a dominant color pattern similar to the one associated with a sample image. This condition can be defined by using the *fuzzy equality operator* to compute the resemblance degree between the fuzzy set of dominant colors which describes each image in the database and the one which describes the example image.

Figure 4 shows an example applied on a database containing about 700 color images. In this case, we are interested in getting images with colors similar to the one showed in the first column. For each image, the query results are shown on the left ordered by relevance.

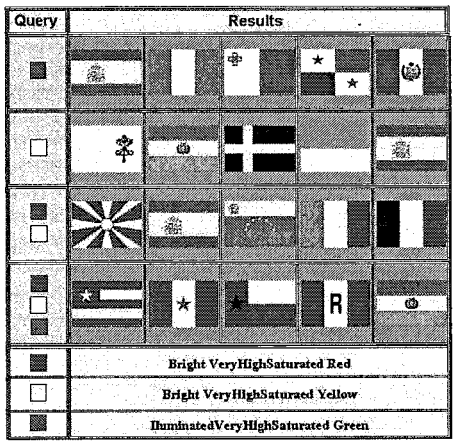

Figure 3: Color inclusion query results using all the color components

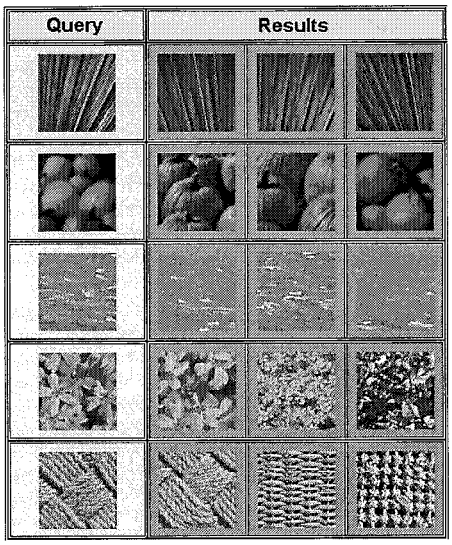

Figure 4: Image resemblance query results

6 Conclusions

This paper has proposed a novel approach for dealing with imprecision in the dominant colors description. For this purpose, the notion of "fuzzy dominant color" has been introduced on the basis of a new definition of fuzzy HSI color space. A methodology to extract the fuzzy dominant colors, as well as the dominance degree, has been presented. On the basis of inclusion and resemblance operators, the dominant fuzzy colors have been used for retrieving images from fuzzy databases. The proposal allows to retrieve of images by means of color linguistic labels, providing a powerful platform for content based image retrieval.

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