

FUZZY COLOR SIGNATURES

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ABSTRACT

With the large and increasing amount of visual information available in digital libraries and the Web, efficient and robust systems for image retrieval are urgently needed. In this paper a compact color descriptor scheme and an efficient metric to compare and retrieve images is presented. An image adaptive color clustering method, called *fuzzy color signature*, is proposed. The original image colors are mapped into a small number of representative colors using a *peaks detection function* derived from the color distribution. Fuzzy color signatures are then used as image descriptors. To compare image descriptors the Earth Mover's Distance is used. The cost associated with the estimation of this metric was modified by applying fuzzy logic. Several experiments have been conducted to assess the performance of the proposed technique.

1. INTRODUCTION

With the large and increasing amount of visual data available, systems that depend on image and video retrieval are facing new challenges in dealing with information overload. The search technologies employed need to be efficient and exploit features that make this environment special. Finding an image on the web is extremely difficult. If images have been manually labelled with an identifying string, e.g. "city centre", then the problem may appear to have been finessed. However, the adequacy of such a solution depends on human interaction, which is expensive and time consuming and therefore infeasible for many applications. Furthermore, such semantic based search is completely subjective and depends on semantic accuracy in describing the image. While a human operator could label an image as "city centre" a second one would prefer the term "traffic jam". Much work on image indexing and retrieval has focused on the definition of suitable descriptors and the generation of metrics in the descriptor space. Although system efficiency in terms of speed and computational complexity has been also subject of research many related problems are still unsolved. Fast, scalable and accurate image indexing and cataloguing

are fundamental requirements of any user friendly and effective multimedia portals.

The use of low-level visual features to search and retrieve relevant information from image and video databases has drawn much attention in the recent years. As a result, several systems have been developed to search through image databases using color, texture, and shape attributes. Texture and color play an important role in the Human Vision System (HVS). The first commercial content-based image search engine using color histograms was QBIC [1], Photo-book added texture and shape features. In the VisualSeek, Netra, and Virage Systems spatial relationships were Included [2]. In the context of distributed databases some image search engines have been also developed. Among others PicToSeek and ImageRover [3] can be stressed. Color histograms have been improved eliminating luminance's Effects [4], incorporating semantic cues [5], including spatial correlation [6], and defining regions of interest [7].

Although color histograms are probably the most important and widely employed image descriptors, their use requires some sort of abrupt quantization leading to information loss. Furthermore, metrics to compare images using histogram descriptors are based on exact matching without considering smooth color transitions in natural images. Consequently, the use of fuzzy logic (FL) to improve efficiency and robustness of search engines appears to be very promising. In this context the Fuzzy C-Means Algorithm [8] can be cited as one pioneering work to cluster image features and overcome exact matching and abrupt quantization problems.

In this work a FL based approach is proposed. First, a "fuzzy" color quantization method is used to map the original color distribution into a small number of relevant image colors using a suitable membership function. This method is called *Fuzzy Color Signature* (FCS). It relies on the detection of peaks in the color distribution function to perform color quantization. The resulting color signature [9] is a very compact, efficient and reliable image descriptor highly suitable for indexing and retrieval in large and distributed

databases. In section 2 a detailed description of this image descriptor is presented.

To compare images using FCS Earth Mover’s Distance [10] is used. The cost associated with the estimation of this metric was also modified by applying FL techniques. This is described in Section 3. In section 4 selected experimental results are reported and the paper concludes with a summary in section 5.

2. IMAGE DESCRIPTOR

In [11] the potential of using color as image descriptors and color histograms for color image indexing was demonstrated. Indeed, color histogram is the most widely used color descriptor in content based retrieval.

Since color histograms capture the global color distribution in an image, it is easy to compute. Unfortunately, it results in large feature vectors and consequently in high computational cost when measuring image similarity. Color clustering is an appropriate method to reduce the complexity of the feature vectors used as descriptors and consequently the computational cost of the retrieval process.

Since the HLS color model resembles the human perception, this model is used in this work. The color distribution C is defined as

$$C = \{\{x_i, f_i\}, i = 1, \dots, n\} \quad (1)$$

where n is the total number of color clusters in the image, x_i is a position in the quantized vector and f_i is its frequency. When the distribution is normalized, the $\sum_i f_i = 1$ and f_i is the percentage of pixels satisfying the condition of the feature represented by x_i .

The number of clusters n is image dependant, the smaller n the lower the dimensionality and complexity of the color distribution. Colors in the original image can be assigned to its closest cluster using the C-Means, Fuzzy C-Means or a Peaks Detection Function.

A signature S_I is a compact color distribution from an image I , denoted by

$$S_I = \{(x_i, w_i)\}_{i=1}^n \quad (2)$$

where the weight w_i gives the strength of color x_i in the image I .

In this work a "fuzzy" clustering method called *Fuzzy Color Signature* is proposed as image descriptor. It is based on the observation that a small number of colors is usually enough

to characterize the color information in an image.

The color signature consists of the representative colors and their relative distribution. To identify these colors the following four functions are used.

2.1. Cumulative distribution function

Each image is transformed from RGB to HSL color space. The cumulative distribution function (cdf) is defined for the hue channel only. The S and L channels are quantized uniformly.

The initial hue vector has 360 values, i.e., 1 degree quantization. For each hue value its corresponding frequency f_i is calculated. The cdf function is defined as:

$$cdf(i) = \begin{cases} 0 & \text{if } i \in (-\infty, 0), \\ \sum_{j=1}^k f_j & \text{if } i \in [0, \dots, 359], \\ \sum_{j=1}^n f_j & \text{if } i \in [360, \infty). \end{cases} \quad (3)$$

where i is a bin in the quantization vector of the hue channel and f_j the frequency of this hue value.

2.2. Average cumulative distribution function

After cdf calculation, the average value $acdf$ of the cdf over a window of size W is estimated. The width W of the smoothing window determines the degree of smoothing and the subsequent sensitivity of peak detection function. The $acdf$ is calculated as follows:

$$acdf(i) = \sum_{j=i-W}^{i+W} \frac{cdf(j)}{2W+1} \quad (4)$$

where W is a small integer number.

2.3. Peaks detection function

The peaks detection function pdf is the core of the cluster method. It allows to estimate modes and peaks in the distribution function. Through zero-crossing values identification, the pdf function detect peak’s ranges, i.e., those positions where peaks start and end. This procedure is close related to the generation of linear scale-spaces for multiresolution analysis. The pdf is defined as:

$$pdf(i) = cdf(i) - acdf(i), i \in \{1, \dots, n\} \quad (5)$$

2.4. Fuzzy mapping function

Once most relevant hue values have been selected using the pdf function, the last step consists of mapping each hue

value into the peak's range to the position of local maximum. To do this, the following membership criterion is applied:

$$w(i) = \sum \mu_{P_i}(j) f_j, \quad j \in P_i \quad (6)$$

where P_i is the range of the peak i and $\mu_{P_i}(j)$ gives the contribution of value j to the peak's energy. If position j coincides with the peak's mode then j has a total membership and $\mu_{P_i}(j) = 1$. If j is outside the peak's range, then $\mu_{P_i}(j) = 0$ or total non-membership. The remainder positions within the peak's range have a partial membership between 0 and 1. The membership function is defined by

$$\mu_{P_i}(j) = e^{-m \frac{\|i-j\|}{\Delta P_i}}, \quad m \geq 1 \quad (7)$$

where ΔP_i is the peaks range and m is a measure of fuzziness.

Applying this clustering method a compact and efficient color signature or image descriptor is obtained.

3. COLOR SIMILARITY

Once image descriptors have been defined the crucial task is to find an appropriate metric in the descriptor space. We propose to use the Earth Mover's Distance (EMD) introduced by Rubner et al [10] as metric to measure the distance between color cells or bins. This allows the user to have different cell sizes so that precision can be kept where required and a coarser approximation can be used when it is not necessary. Observe that for a given smoothing window W the size of image descriptors change according to the image content. The EMD reflects the minimal amount of work that must be performed to transform one feature vector into the other by moving the distribution mass around. Intuitively, given two n -dimensional vectors one of them can be seen as the mass of earth spread in space and the other as a collection of wholes in the same space. The proposed metric measures the least amount of work needed to fill the wholes with earth. The EMD is obtained as follows:

$$EMD(p, q) = \frac{\sum_{i=1}^n \sum_{j=1}^m C_{ij} \|p_i - q_j\|}{\sum_{i=1}^n \sum_{j=1}^m C_{ij}} \quad (8)$$

4. EXPERIMENTAL RESULTS

To assess the performance of the presented approach several experiments have been conducted. A database containing several thousands of images has been used. Fig. 1 outlines the different modules and processes involved in the indexing and retrieval system.

In Fig. 2 the query is shown at the upper-left corner (image #10871). The most similar images extracted from the

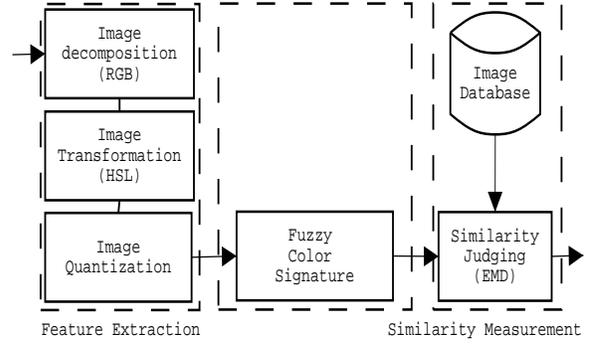


Fig. 1. Indexing and Retrieval using FCS

database using the proposed technique along with their similarity value are displayed in ascendant order.

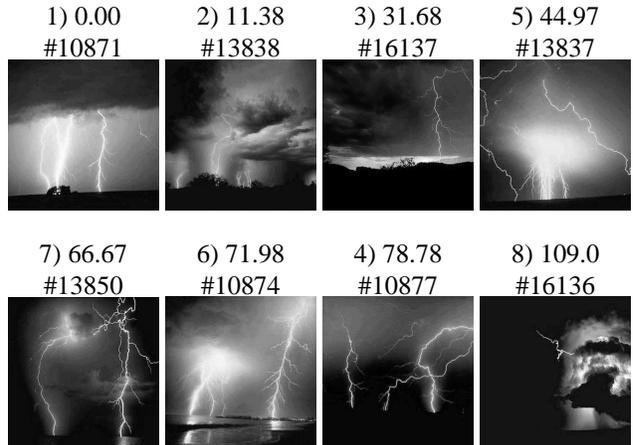


Fig. 2. Retrieval results

Fig. 3 gives the results of applying the *cdf*, *acdf* and *pdf* functions to image #10871. In this Fig. 3 the vector quantization shows that the highest frequencies are between 250–359, Table 1 lists the color distribution for few positions including the highest frequency: $\langle 259, 111417 \rangle$.

x_i	12	150	165	259
w_i	26209	54	23	111417

Table 1. color signature for the 10871 image

5. CONCLUSION AND FUTURE WORK

In this work, a compact color-based image descriptor is proposed. The descriptor is based on the distribution of representative colors in the image. It determines the introduced *fuzzy color signature*. This signature is robust in describ-

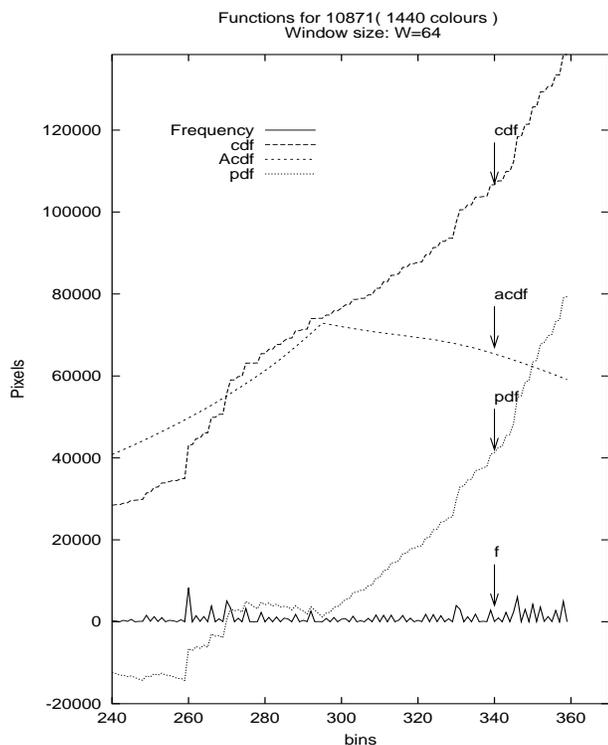


Fig. 3. cdf, acdf and pdf functions for the 10871 image

ing color image primitives and can be used for efficient image retrieval in large fixed and distributed databases. It is estimated using four basic functions: cumulative distribution function (*cdf*), average cumulative distribution function (*acdf*), peaks detection function (*pdf*) and fuzzy mapping function (*fmf*). Their calculation is straightforward and computationally inexpensive.

The conventional Earth Mover's Distance is modified and used as similarity measure. The cost calculation of the improved metric is based on a "fuzzy" membership function providing better retrieval results without overloading the system.

Regarding the implementation of a complete image Portal, several schemes and user preferences can be considered using the presented approach. For instance, the user can: query images with at least 30% blue and 10% red, outline the query by painting it in a simple icon- or cartoon-like form or, give an query example and search for similar images (the usual query-by-example paradigm.)

One limitation of the presented system is that it does not handle spatial relationships of colors in the image. Since the spatial distribution of colors is also an important source of information, it will be considered in further developments.

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