An Efficient Perceptual Color Indexing Method for Content-based Image Retrieval Using Uniform Color Space

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Abstract. Dominant Color Descriptor (DCD) is one of the famous descriptors in Content-based image retrieval (CBIR). Sequential search is one of the common drawbacks of most color descriptors especially in large databases. In this paper, dominant colors of an image are indexed to avoid sequential search in the database where uniform RGB color space is used to index images in LUV perceptual color space. Proposed indexing method will speed up the retrieval process where the dominant colors in query image are used to reduce the search space. Additionally, the accuracy of color descriptors is improved due to this space reduction. Experimental results show effectiveness of the proposed color indexing method in reducing search space to less than 25% without degradation the accuracy.

Keywords: Color indexing, Dominant color descriptor, LUV color space, RGB color space, Database search space.

1 Introduction

Image retrieval become one of the most famous research directions nowadays because it uses to search an image in archive, domain-specific, personal and web image databases. For retrieving images from multimedia database, low level features and especially color feature, have been widely used in this regard. This is because color represents the most distinguishable feature compared with other visual features, such as texture and shape [1-3]. From perspective of feature extraction, color-based image descriptors can be divided into two categories: (i) global descriptors that consider the whole image to obtain their features, there is no partitioning or pre-processing stage during feature extraction process and (ii) local descriptors that obtain their features from local regions or partitions of image. This can be achieved by dividing the image into either fixed-size or different-size regions. These descriptors usually have better accuracy than others but introduce more complexity of feature extraction process.

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In this respect, MPEG-7 committee proposed many color, texture and shape descriptors to be used in image and video retrieval [4]. Human visual system as mentioned in [5, 6] firstly identifies prominent colors in the image then it processes any other details. MPEG-7's DCD provides compact and effective representations for colors in an image or region of interest [4]. Recently, compactness property of dominant colors representation becomes more attractive for many researchers to reduce size of color descriptors from several hundred bins (histogram-based methods) into few colors (8 colors as in MPEG-7 DCD) such as the works that have been achieved in [3, 7, 8].

Recently, researchers focus on either retrieval robustness (retrieval accuracy) or retrieval efficiency (retrieval speed) [9]. Basically, the searching a large images database imposed delay of image retrieval process. Therefore, this paper focuses on the retrieval efficiency that is closely related to the retrieval robustness. Color histogram and dominant color descriptors are the widely used methods in content based image retrieval [2, 3]. Histogram suffers from high-dimensional indexing problem, hence color quantization techniques are used for color reduction but fixed quantization lead to accuracy degradation because different colors may be mapped to the same quantized color bin. Therefore, dominant colors (DCs) extraction methods (a dynamic quantization approach) were proposed as the most effective solutions in this context where few colors are extracted to represent the image. DCs are proposed for image indexing in this research, but it suffers from "color approximation" problem. Another issue that need to be mentioned here, the characteristics of RGB color distribution is uniform; it is simple and straightforward color representation, however is not a perceptual color space [10]. Perceptual color spaces match human visual system and have non-uniform color distribution such as LUV, Lab and YUV. As a result of this, complicated and time consuming quantization methods must be used for these perceptual spaces. For perceptual color indexing, two methods can be used which are color clustering such in [11, 12] or utilizing uniform color spaces [13]. The shortcomings of these two methods can be summarized as follows: (i) color clustering methods (such as k-Means and adapted version of k-Means [14]) have color approximation problem and (ii) utilizing uniform quantization (such as *Octree* [15]) for perceptual (non-uniform) color spaces will not take into account the perceptual similarity between different bins. RGB and HSV color spaces do not exhibit perceptual uniformity whereas LUV, Lab and YUV color spaces have this perceptual effect. Therefore, from all above cited problems, perceptual color indexing method is proposed.

The paper is organized in the following way. Section 2 explicates the general CBIR indexing methods and specifically color-based indexing methods. Section 3 is mainly concerned with the proposed indexing method and the newly proposed color percentage filtering scheme that helps improve and speed up the retrieval process. Section 4 illustrates the quantitative results of experiments that conducted to show the effectiveness of proposed indexing method. Finally, the conclusion can be seen in Section 5.

2 Related Work

In large image database, indexing is an urgently demanded to reduce the search space of the retrieval process and in turn to speed up the process. For indexing the image features, there are two main approaches in general: multi-dimensional indexing and vector quantization techniques. Multi-dimensional indexing is divided into two approaches namely space partitioning (SP) and data-partitioning (DP). Both of them divide the space into small partitions. SP divides the whole space into disjoint partitions without consideration of the data (feature vectors). In DP methods, feature space is divided depending on features (data) distribution in the database. The advantage of SP method is it performs complete and disjoint partitions of the whole space that means there is no overlapping between these partitions. Disadvantage of SP method occurred when the query point locates at the border of partition. This will lead to degrade the retrieval performance at least in two situations: a) retrieval accuracy will decrease if the search on this point was made within that partition only and there are some similar points in neighbor partitions due to ignoring some similar points in the search space or b) computational will increase if all neighbor partitions are taken into account where the search space will increase after considering many partitions and many unrelated data will be compared.

In vector quantization techniques, there are many color clustering techniques that have been proposed including hierarchical k-Means clustering, randomized tree and self-organizing map. In these methods, no partitioning of space involves, instead grouping the data into clusters or groups. The properties of these clusters are the distance between minimizing the intra-cluster members whereas the distance between the different inter-clusters should be maximized. Each cluster is represented by a cluster's centroid, thus the query point is compared with cluster's centroid instead of original value of the members. Disadvantages of these methods are the initial number of clusters, *k* needs to be known prior. Additionally, majority of these methods do not preserve ordering structure of data space. This will lead to expensive online distance computation with all clusters' centroids to select the nearest one. Moreover, comparing with clusters' centroids instead of original values lead to inaccurate results because some cluster's members are far from the query points in spite of having suitable distance from cluster's centroid which known as "color approximation problem".

For 3-D color indexing, several methods have been proposed in CBIR field. High dimensional histogram indexing method, that is used by [16] for comparison, is considered as the simplest and most expensive indexing method. This method suffers from high dimensional problem, 1024-D of color histogram bins. Combination of color clustering and spatial indexing method (R-Tree) for color indexing can be seen in [11]. A method proposed by [12] on color clustering and indexing by using the mean shift algorithm for color clustering, R*-Tree for spatial indexing and perceptually uniform LUV color space. The above two methods depend on clustering that are suffered from aforementioned problems of clustering (one of VQ techniques). NeTra system proposed by [17], used binary color table for color indexing that depended on 256 colors codebook in RGB color space. However, restricting with 256 colors certainly will lead to accuracy degradation as a result of color quantization (similar to color quantization method for histogram).

In general, color-based indexing methods depend on fixed range of colors in similarity measure. Therefore, spatial indexing methods such as R-Tree and R*-Tree are not necessary and fixed indexing structure is more efficient [16]. Accordingly, Lattice structure [16] is characterized by efficient finding the nearest neighbors of given point (color) in 3-D LUV color space. Nevertheless, this efficiency depends on careful selection of radius in hexagonal lattice cell and this is not a straight forward process, hence there is no comparison (in the literature) has been made with this method. Additionally, it suffers from same problem of SP and clustering methods, as the query point may locate at the border of lattice cell, as depicted in Fig. 1. Moreover, lattice structure has better performance in uniform distribution than non-uniform distribution [18]. Thus, it is recommended for RGB color space instead of LUV color space.

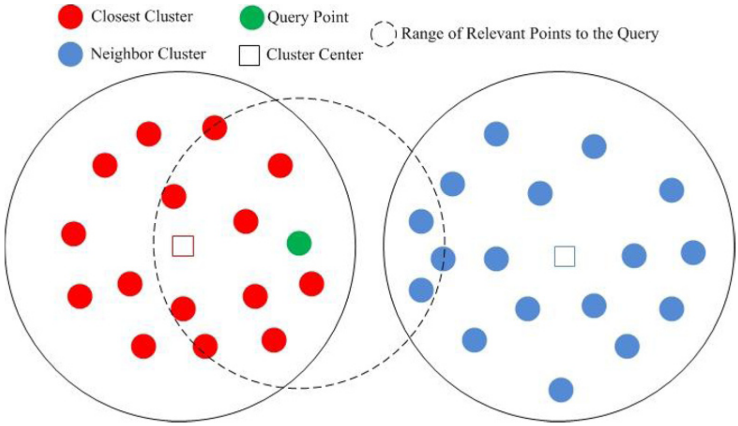

Fig. 1. "Locating query at the cluster border" problem.

Recent research is proposed by [14] to solve this problem. The significant contribution of that research was introducing two threshold values C_G and C_S that can be considered as search space parameters to improve searching process.

As conclusion, all vector quantization indexing methods, which most color indexing methods are depended on, suffered from color approximation problem. Therefore, this problem is addressed in this paper.

3 Proposed Indexing Method

In this section, DC-based indexing method is proposed to reduce search space of color-based methods (i.e. it dedicates to all color-based methods, not only DC-based methods) to speed up retrieval process as well as preserve or increase retrieval accuracy. This paper mainly working on of reducing the search space rather than doing whole database search. For that, a fixed space partitioning method is used in this research. Before building database index structure, similarity between two colors must be considered and maximum distance between these colors also needs to be determined because the index structure will depend upon them.

3.1 Indexing Structure of Maximum Distance

The key of the proposed method is a similarity among colors within fixed range. The searching can be done only in a specific range within distance, which is the maximum distance between two colors to consider them as similar colors. The Euclidian distance between two *3-D* colors to assume them similar was 10, 20 or 25 [4, 5]. Therefore, the maximum difference value (MxDV) for each color channels (Red, Green and Blue in RGB color space) is set to 25.

In DC-based methods (e.g. MPEG-7 DCD), DCs are extracted using dynamic quantization method (GLA) and most likely the image is quantized to most significant 5-bits of color channels (bit3 to bit7). Since the maximum difference between two channels is 25, the changing of the two bits (bit3 and bit4) is within this range. This because the weights of these bits are 8 and 16 respectively; their summation is 24 that approximately equals to MxDV (25). In this regard, bit7, bit6 and bit5 are out of tolerance range of colors to be similar. Thus, these three bits are the first level of color similarity; they are used to differentiate among not similar colors. The other two bits (bit3 and bit4) are used separately to be second and third level respectively of color similarity. Hence, first indexing dimension contains 512 cell (3-bits from each channel = 9-bits, no. of cells = $2^9 = 512$). Second indexing dimension contains 8 cells (1-bit from each channel = 3-bits, $2^3 = 8$). The third dimension has 8 cells that represent the remaining one bit (bit3), as presented in Fig. 2.

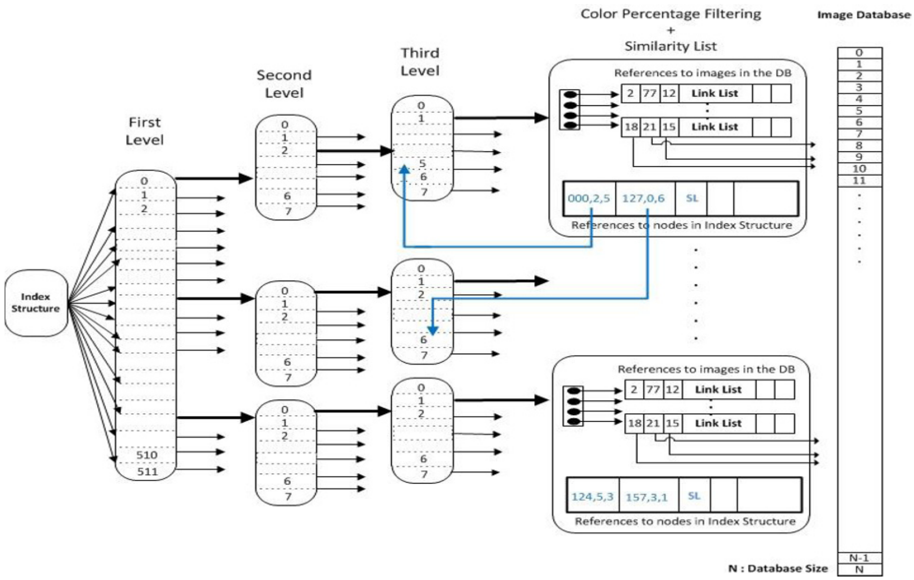

Fig. 2. Proposed indexing method for perceptual color spaces.

Color percentage plays an important role in similarity measure of certain color with its corresponding color in other images where the similar colors consider as dissimilar if their percentages have large difference such as similarity measure of different color descriptors such as MPEG-7 DCD, LBA [5], BIC [19], and Correlogram [20]. Therefore, filtering images (that have large difference in percentage) in early stage helps in reducing search space and in turn speeding up the retrieval process. Deng [16] used filtering process during query processing. This online filtering is impractical because it is time consuming. Therefore, the proposed indexing structure is extended to include partitions of color percentages. Single level B+-tree [21] is used to represent color percentages. B+-tree can be added to all leaf nodes (in the third index level), as shown in Fig. 2. To achieve the perceptual concept of LUV color space, LUV color distance is used. Each color in the 5-bits quantized space (each node in the third level of the index structure) is compared with other colors in the space and stores the perceptually similar colors in a list (similarity list) that belonging to this color as depicted in Fig. 2. The searching for similar colors does not include all color space; instead, it searches within specific range in the whole color space. This range depends on the color similarity thresholds where the similarity between each two colors must be less than or equal the certain color threshold. Color thresholds that are selected in this research are 10, 15, 20 and 25.

3.2 Searching Process

In this process, a query is required to find its similar images in the database. Searching process includes the following steps:

1. For each DC in the query image, find database images that have similar in both color and percentage; this is by reaching to the single node in the index structure and in turn to the database images that are associated with this node.
2. In each single node (of point 1) that corresponds to each DC in the query, there is a similarity list that is used to reach all similar colors in LUV color space. It contains references to all nodes (colors) in the index structure and thus to all images that contain similar colors of the query image.
3. Merging images that resulted from each DC of the query image to produce search space of the query, it represents Reduced Search Space (RSS).
4. Calculate dissimilarity distance between query and all images in the RSS, and then rank them accordingly.

In step 1, images that have same DCs of the query are reached. In step 2, all images that have perceptually similar colors to the query DCs are collected to produce RSS. It is worth mentioning, step 1 and 2 also filter the images that have different color percentages using B+-tree that exists in each node in the index structure. This helps reducing the search space that is emerged in step 3. Dissimilarity distances (of specific descriptor) are computed to all images in the RSS to obtain the most similar images to the query. The important characteristics of the proposed index structure are it uses to index RGB and LUV color spaces; it is dynamic to the database updating process (insertion and deletion). Lastly, it does not have any color approximation.

4 Proposed Indexing Method Performance

Performance of the proposed technique is evaluated based on the following:

1. ***Number of Indexed colors:*** Indexing of images database can be performed with different numbers of colors (8, 5, 3 or 1) to measure the effect of each one on the retrieval performance. The database is indexed firstly according to maximum DCs in the image that equal 8; then reduce the number of indexed DCs into 5, 3 and 1. It is noteworthy to mention here that DCs is sorted in descending order according to their color percentage before the indexing process.
2. ***Evaluation Metrics:*** Two types of metrics are used in this research:

(a) Efficiency Metrics: The main goal of indexing is to reduce search time compared to sequential search by reducing database images that can matched the query image. It eliminates unlikely (irrelevant) images from the matching process to produce RSS. The reduced time needed for searching in the RSS can be computed by the percentage RSS/WSS, WSS denoted to the Whole Search Space. The percentage RSS/WSS% can be called as Search Space Ratio (SSR) that represents ratio of images that are actually searched to the all images in the database.

(b) Accuracy Metrics: Three quantitative performance metrics are utilized to measure the accuracy of different color descriptors that are used in the proposed indexing method. These metrics are ARR, ANMRR and P(10).

3. ***Evaluation Datasets:*** Evaluating the proposed indexing techniques will be conducted on two datasets, newly introduced Cartoon-11K (11,120 images) and well-known Corel-10K (10,800 images). These datasets are different in terms of image content (color and variety) as well as their sizes are large enough to fit the objective of designing the indexing methods. The main dataset in this research is cartoon dataset that is used to evaluate color descriptors. This is because the characteristic of the most cartoon characters is appearing with the same colors in all or most images [22, 23].
4. ***Competing Indexing Methods:*** Indexing methods that are selected to compete with the proposed method are sequential search, k-Means (KM), and recent k-Means with B+-tree methods (KMB) [14]. Sequential search is a conventional method in CBIR for searching in the database. The accuracy resulted from sequential search is considered as optimal accuracy because searching in this method include whole database. Therefore, all competing indexing methods accuracies are compared with it to check the degradation that can be obtained from these methods due to the reduction of search space.
5. ***Evaluation Color Descriptors:*** the color descriptors that can be used to test the proposed indexing method are MPEG-7 DCD and Color Correlogram (*ColGrm*). MPEG-7 DCD is used because it contains dominant colors whereas the Correlogram is complicated color descriptor and it is general color descriptor (it does not have dominant colors). This is to prove that the proposed indexing method can be generalized for all color descriptors not just for DCDs.

Table 1. Performance metrics for *ColGrm* descriptor using sequential search, KM, KMB, and proposed LUV indexing method applied on Cartoon-11K Dataset with 158 Queries.

ColGrm	Indexed color = 8		Indexed color = 5		Indexed color = 3		Indexed color = 1	
	P(10)/ ARR/ ANMRR	% SSR	P(10) / ARR/ ANMRR	% SSR	ARR/ ANMRR/ P(10)	% SSR	P(10) / ARR/ ANMRR	% SSR
Sequential Search	0.350/ 0.118/ 0.852				100%			
KM	0.310/ 0.100/ 0.874	45.8	0.320/ 0.102/ 0.872	40.8	0.270/ 0.089/ 0.889	24.1	0.220/ 0.076/ 0.905	14.5
KMB	**0.350/** 0.115/ 0.856	76.6	**0.350/** 0.116/ 0.856	71.0	0.310/ 0.104/ 0.870	39.8	0.230/ 0.080/ 0.899	26.7
LUV Indexing,	**0.350/**	**90.5**	**0.360/**	**82.1**	**0.360/**	**69.6**	0.360/	45.6

Color threshold = 25	**0.118/ 0.852**		**0.119/ 0.851**		**0.120/ 0.851**		0.117/ 0.855	
LUV Indexing, Color threshold = 20	**0.360/ 0.120/ 0.850**	**78.0**	**0.360/ 0.121/ 0.850**	**68.0**	**0.360/ 0.121/ 0.849**	**54.4**	0.340/ 0.114/ 0.859	31.4
LUV Indexing, Color threshold = 15	**0.360/ 0.122/ 0.848**	**59.4**	**0.360/ 0.122/ 0.848**	**51.4**	**0.360/ 0.122/ 0.847**	**41.6**	0.340/ 0.114/ 0.860	25.8
LUV Indexing, Color threshold = 10	**0.360/ 0.120/ 0.849**	**37.1**	**0.360/ 0.121/ 0.849**	**33.0**	**0.360/ 0.117/ 0.854**	**28.2**	0.330/ 0.107/ 0.867	19.8

Note: Bold values represent the accuracy values that are better than or equals to sequential search.

Table 1 shows the results of all the indexing methods using ColGrm descriptor applied on Cartoon-11K dataset with 158 queries. Accuracy of the results using LUV indexing method is better than those of sequential search, KM and KMB in most settings (in four LUV color distances 25, 20, 15, and 10 as well as in different indexed colors 8, 5, 3). This leads to retrieve all images that have similar colors (to the query DCs) where there is no color approximation at all. The unique case that has accuracy less than that of sequential search is when using 1 color for indexing.

SSR of the proposed LUV indexing method is ranged from high search space (the worst) to very low search space. The worst case occurs when LUV color distance equals to 25 (it is similar to KMB) where both of them have large SSR. The medium case occurs when distance equals to 20 (it lower than KMB and higher than KM). The lower case occurs when LUV distance equals to 15 (it similar to KM). The very low search space (the best) case (lower than KM) occurs when the distance equals to 10 with SSR equal 19% without degradation to the accuracy. According to these different search space ratios of different settings of LUV indexing method, the accuracy of it is higher than sequential search and all other indexing methods (except when indexed color equal 1) with reduction the search space to less than 20%.

Experiments on MPEG-7 DCD also show similar accuracy to the *ColGrm* descriptor. This ensures effectiveness of the proposed indexing method in different color methods. Performance of the experiment as represented in Table 2.

Table 2. Performance metrics for MPEG-7 DCD using sequential search and all indexing methods including proposed LUV indexing applied on Cartoon-11K Dataset with 158 queries.

MPEG-7 DCD	**Indexed color=8**		**Indexed color=5**		**Indexed color=3**		**Indexed color=1**	
	P(10)/ ARR/ ANMRR	% SSR	P(10)/ ARR/ ANMRR	% SSR	P(10)/ ARR/ ANMRR	% SSR	P(10) / ARR/ ANMRR	% SSR
Sequential Search	0.230/ 0.060/ 0.922				100%			
KM	0.200/ 0.057/ 0.926	45.8	0.210/ 0.059/ 0.926	40.8	0.180/ 0.051/ 0.935	24.1	0.140/ 0.041/ 0.947	14.5
KMB	**0.230/** 0-.059/ **0.922**	76.6	**0.230/** 0.059/ 0.923	71	0.210/ 0.056/ 0.927	39.8	0.150/ 0.042/ 0.945	26.7
LUV Indexing, Color thresh-old =25	**0.230/ 0.060/ 0.922**	**90.5**	**0.240/ 0.060/ 0.922**	**82.1**	**0.240/ 0.061/ 0.922**	**69.6**	**0.240/ 0.060/ 0.922**	**45.6**
LUV Indexing,	**0.240/**	**78.0**	**0.240/**	**68.0**	**0.240/**	**54.4**	**0.230/**	**31.4**

Color thresh-old =20	**0.060/ 0.922**		**0.060/ 0.922**		**0.060/ 0.922**		**0.060/ 0.923**	
LUV Indexing, Color thresh-old =15	**0.240/ 0.060/ 0.922**	**59.4**	**0.240/ 0.060/ 0.922**	**51.4**	**0.240/ 0.060/ 0.922**	**41.6**	0.230/ 0.059/ 0.924	25.8
LUV Indexing, Color thresh-old =10	**0.240/ 0.061/ 0.922**	**37.1**	**0.240/ 0.061/ 0.921**	**33.0**	**0.240/ 0.059/ 0.923**	**28.2**	0.230/ 0.057/ 0.926	19.8

5 Conclusion

In this paper, indexing methods of CBIR with advantages and disadvantages of each method are presented. Specifically, the problems of color-based indexing methods such as high-dimensional problem for histogram-based methods and color approximation problem of DC-based methods are addressed. Accordingly, DC-based indexing method is proposed where it dedicates for non-uniform LUV color space. The proposed method has similar superiority of SP methods with some enhancements. The supremacy of the proposed LUV method over SP is overcoming the problem of locating the query on the border of partitions (or cluster) and preserving the perceptual distance between colors in the color space. Additionally, existence the static representation (array) of index structure and color percentage filtering scheme (using B+-tree) help with speed up the retrieval process.

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