2017 International Conference on Computing, Communication and Automation (ICCCA 2017)

Greater Noida, India
5-6 May 2017

Pages 1-788

IEEE Catalog Number: CFP17IWY-POD
ISBN: 978-1-5090-6472-4

****** This is a print representation of what appears in the IEEE Digital Library. Some format issues inherent in the e-media version may also appear in this print version.***

IEEE Catalog Number: CFP17IWY-POD
ISBN (Print-On-Demand): 978-1-5090-6472-4
ISBN (Online): 978-1-5090-6471-7

Additional Copies of This Publication Are Available From:

Curran Associates, Inc
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: (845) 758-0400
Fax: (845) 758-2633
E-mail: curran@proceedings.com
Web: www.proceedings.com

Contents

Track–1

Web Intelligence & Semantics, & Data Mining

Track 2

Evolutionary Computing

Track 3

Ubiquitous Computing & Networking

Track 4

Distributed Computing & Cloud Computing

Track 5

Software Engineering & Information System

Track 6

Intelligent System & Automation

Track 7

Multimedia Services & Technologies

Track 8

Green Computing & Internet of Things

Track 9

Hardware Design and Communication

An Enhanced CBIR using HSV Quantization, Discrete Wavelet Transform and Edge Histogram Descriptor

Mohd. Aquib Ansari
Dept. of CSE/IT
Madhav Institute Technology & Science,
Gwalior, India
aaquib.mits@gmail.com

Manish Dixit
Dept. of CSE/IT
Madhav Institute Technology & Science,
Gwalior, India
dixitmits@gmail.com

***Abstract*— Now a days, a great attention has received for content-based image retrieval by the researchers. It is very popular and interesting topic of computer vision. The basic requirement of content based image retrieval is to extract the appropriate information from the large image repository corresponding to query image on the basis of contents with better system performance. But, in the development of CBIR system with an appropriate fusion of low-level features is a big problem. This paper suggested an enhanced retrieval system by using the combination of HSV histogram, discrete wavelet transforms and edge histogram descriptor to extract the relevant information of an image. In this work, we used HSV color histogram with quantized non-uniform 72 bins to extract color information of image, discrete wavelet transform on each component (H, S and V) of HSV image to extract the complex texture pattern of image and global as well as local edge histogram descriptor on V component of HSV image to extract the geometry information of image. Here, Euclidean distance is used as similarity measurement to find out how similar the user image is with respect to the image in the database. For experimental analysis, 600 images of Wang image database are used and the results show that this approach gives good performance in term of precision and adaptableness while comparing with other's combining scheme.**

Keywords*— *CBIR; HSV histogram quantization; discrete wavelet transform; edge histogram descriptor.

I. INTRODUCTION

In the era of computer vision with the wide spread of internet and the availability of the picture capturing devices (such as. Digital Camera, Digital Scanner etc.), the collection of digital images is growing day by day. Now, it becomes more important to search images that containing user's query image related characteristics from the huge image database. Therefore, there is need to develop an efficient technique on which it automatically searches the desired image effectively. Thus, to fulfil these requirements, the image retrieval technique is used [1] [2]. The basic aim of retrieval system is to find out the appropriate images from the huge image digital library corresponding to query image pattern. The basic two approaches of image retrieval are Text Based Image Retrieval (TBIR) and Content Based Image Retrieval (CBIR) [4]. TBIR is a fast and reliable technique but it depends on image annotation and size of image database space [3].

CBIR is an improved as well as efficient approach of image retrieval system because it performs image retrieval on the basis of visual contents rather than metadata (like keyword, tags, descriptors etc.) linked with the digital image. These visual contents (like color, texture and shape) are also called as a low level or pixel level features. These low level features are extracted from image database to form the feature vector, further this feature vector is used to compare with query image feature vector for retrieval of images [5] [6].

Here, we attempted to develop an efficient cbir system by using our proposed methodology and performed the experimental analysis by comparing it with other's existing methods. There are several sections in this paper. Section II explains related work of various researchers in CBIR. Section III describes about HSV histogram, wavelet transform and edge histogram descriptor with our proposed work. The experimental work is done in section IV. Sections V mentions conclusion with the future scope of this work followed by references.

II. EXISTING TECHNIQUES OF CBIR

In 2011, M. Babu Rao [7] developed an efficient algorithm for cbir systems by using the fusion of dynamic dominant color, motif co-occurrence matrix and difference between pixels of scan pattern. Here, for color evaluation, the digital image is partitioned into eight partitions to extract eight dominant colors of image. For texture evaluation, motif co-occurrence matrix and difference between pixels of the image pattern is used to represent the orientation of texture. On the basis of these features, they developed an efficient retrieval system which is more relevant in retrieving user perspective images.

In 2012, Aman Chadha and sushmit mallik [8] surveyed the various low level feature extraction techniques of cbir in context of system parameters like time, accuracy and redundant factor. They performed the experimental analysis on each individual approach of feature extraction techniques

ISBN: 978-1-5090-6471-7/17/$31.00 ©2017 IEEE

and find that the combined approach produces better result than individual approaches. This paper also suggested the new method for query image alteration by the help of cropping to retrieve more relevant images from the large image libraries.

In 2013, Pranoti Mane [9] performed the comparative study on the edge histogram descriptor as well as color structure descriptor. The comparative evaluation is performed on the different type of images of wang database and found that the combination of edge histogram descriptor with color structure descriptor is performing well than single feature descriptor.

In 2013, Swati Agrawal, A. K. Verma and Preetvani Singh [10] described an efficient method for content based image retrieval by using edge histogram algorithm as well as two level discrete wavelet transform. Here, Edge histogram algorithm is applied on each component of wavelet transform and performed that algorithm on to several types of image databases. This combination of text and shape based feature descriptors has increased the accuracy of the system in retrieving the images from huge image database.

In 2014, Srikant Redrouthu, Annapurani. K [11] presented a modified approach for CBIR system by using combination of multiple features. The color as well as shape feature descriptors are used in this approach. This paper also performed the comparisons of time among each of the features and combine feature approach for CBIR system.

In 2016, Yogita Mistry, D. T. Ingole, and M. D. Ingole [12] proposed an improved method for retrieval system. In this paper, they used the fusion of discrete wavelet transform and linear binary partition technique to analyse spatial as well as texture pattern information of the image and found the good accuracy and performance in CBIR system.

In 2016, Rajkumar Jain and Punit Johri [13] introduced the combine feature of quantized HSV Histogram with 72 non uniform bins to extract color features as well as prewitt edge extraction technique to evaluate the edge information of image for the cbir system. In this paper, Manhattan measurement is used and showed that the fusion of these features performs well in precision.

III. PROPOSED SYSTEM

Feature extraction is most essential phenomenon of image retrieval system. By selecting of finest feature descriptors, it uses to attain the greater accuracy and performance to extract the images from the image database. It depends on the visual content of an image. These calculated feature vectors of the image are kept in to the database and then perform the comparison between the input image feature vector and every feature vector of image database [14].

Feature extraction is a process to extract the features (color, texture and shape) from the image and construct feature vector that uniquely describes the image. Here, we need to combine these feature descriptors to make an efficient system [15].

A. HSV Color Histogram Quantization

Color Histogram is used to define the distribution of color within an image. In this paper, we used the Quantized Color Histogram algorithm to extract the color feature from the image. First, we need to quantize the number of bins of Histogram. HSV quantization method is based on thresholding that is used to quantize the value of Hue, Saturation and Brightness [6] [13].

For Saturation and Value

If, $0 <= (S, V) < 0.2$, value of pixel = 0 (black).

If, $0.2 <= (S, V) < 0.7$, value of pixel = 1.

If, $0.7 <= (S, V) < 1$, value of pixel = 2.

Similarly, For Hue

If, HЄ [315, 360], value of pixel = 0 (Black).

If, HЄ [0, 25], value of pixel = 1.

If, HЄ [26, 40], value of pixel = 2.

If, HЄ [41,120], value of pixel = 3.

If, HЄ [121,190], value of pixel = 4.

If, HЄ [191,270], value of pixel = 5.

If, HЄ [271,295], value of pixel = 6.

If, HЄ [296,314], value of pixel = 7.

Now, these values are replaced by histogram bins. HSV color histogram quantization is used to extract minimum number of feature to represent an image properly. It is computationally efficient also. Here, every Component of HSV model such as H, S and V is quantized with respect to thresholding function. Then we combined this histogram into 8x3x3 (H into 8 bins, S into 3 bins, V into 3 bins) and we will obtain 72 dimensions of vector [1] [17].

B. Discrete Wavelet Transform

The term Wavelet refers to small waves of varying frequency with finite duration. Wavelet is based on the multi-resolution analysis. The image of an object is measured as metrics of pixel's intensity values. The high resolution and large size object can be observed by small size object and low contrast. The one of the biggest advantage of multi-resolution approach is that the feature of the image that could not be identified at one resolution it can be identified in another resolution [18].

Discrete wavelet transform transforms time domain signal into the time domain as well as frequency domain signal. Transformation of the time domain signal is also be called translation. Translation is based on the window function. Where window is movable with respect to arriving signal. Scale is one of the method of frequency transformation. It is proportional to inverse of frequency value. Discrete wavelet transform is better texture retrieval due to its closeness to Human Visual System as well as its bit error rate is slow also [19] [20]. In wavelet transformation, filters are applied on

each level of discrete signal. Each level is evaluated by taking the previous level approximation coefficient using discrete time low and high pass filter [21]. Figure 1 shows the decomposition process with distinct level 1, 2 and 3.

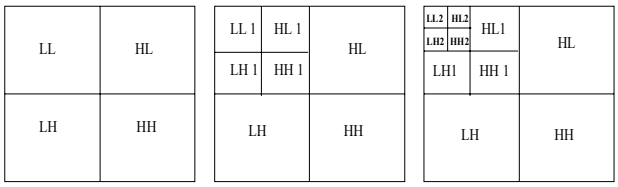


Fig. 1. Wavelet decomposition on image

In DWT, the image is divided into 4 sub-bands with decomposition level 1. These 4 bands are approximation coefficient (LL), horizontal coefficient (HL), vertical coefficient (LH) and diagonal coefficient (HH). Then over again LL is decomposed into LL1, HL1, LH1, HH1 and so on [22]. Here, DWT is used to extract the complex textures patterns of the image.

C. Edge Histogram Descriptor

Edge Histogram Descriptor (EHD) is an edge based feature extraction technique, defined by MPEG-7 standard, which is used to describe the geometry of the image. In our paper, we used Local EHD as well as Global EHD to extract the shape information of an image. EHD is used to describe the orientation of edges within each sub-image [23]. Edge Histogram Descriptor classifies the edge's orientations into 5 classes: (a) vertical orientation, (b) horizontal orientation, (c) 45-degree orientation, (d) 135-degree orientation and (e) no-direction orientation of edge. The different edge's orientations are shown in figure (2) [25].

Fig. 2. Type of edge direction with mask

The local EHD can be calculated by partitioning the image into 16 equal parts (called sub-images) and then calculate the edge orientation for each part of the image [9] [24]. Each of sub-image having 5 bins of histogram with respect to existing edge orientation type.

Figure 3 illustrates subdivided image structure having 16 sub-images. To identify the different orientations of edges type, each sub-image is partitioned again into equal size image-blocks. Then semantic of local edges oriented within an image is calculated. Edge orientation is determined by each image-block of 2x2 pixel size, then apply masking on image-blocks of each sub-image and evaluate following to the algorithm of EHD [25]. Hence, a total number of bins of local EHD in each image is 80 bins. Table I Describes the semantics of bins [27].

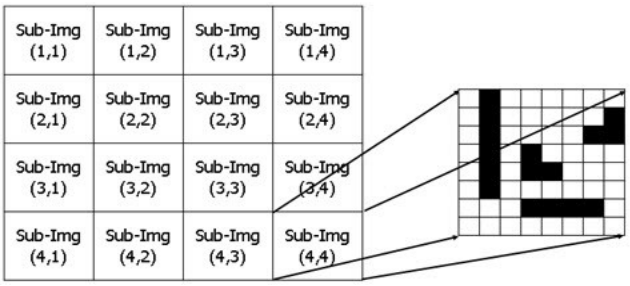


Fig. 3. Example of partition of image with image block

TABLE I. SEMANTICS OF EHD BINS

Bins	Sub-image number	Semantics
Local-EHD[0]	(0, 0)	Vertical Edge
Local-EHD[1]	(0, 0)	Horizontal Edge
Local-EHD[2]	(0, 0)	45 Degree Edge
Local-EHD[3]	(0, 0)	135 Degree Edge
Local-EHD[4]	(0, 0)	No-Direction Edge
.	.	.
.	.	.
.	.	.
Local-EHD[76]	(3, 3)	Vertical Edge
Local-EHD[76]	(3, 3)	Horizontal Edge
Local-EHD[77]	(3, 3)	45 Degree Edge
Local-EHD[78]	(3, 3)	135 Degree Edge
Local-EHD[79]	(3, 3)	No-Direction Edge

To gain high retrieval efficiency, sometimes the result might not be good by using local color histogram [26]. It might be required to calculate edge distribution for the entire image. So, besides the local histogram, we need to calculate global histogram. The global based EHD evaluates the global edges distribution for the whole image. The bin value of global EHD will be 5 for five type of edge orientation. Thus we have 80 bins for local EHD and 5 bins for global EHD (total=85 bins).

D. Proposed Algorithm

Step 1: Input the query image.

Step 2: Perform the Pre-processing step on the image. First, resize the image to 256 X 384 and then transform it from RGB image to HSV image.

Step 3: Apply the Quantized HSV Histogram on complete HSV Image and construct feature vector (fv1).

Step 4: Apply Wavelet Transform on each separated H, S, and V Components of HSV Image and construct feature vector (fv2, fv3, fv4) from each component.

Step 5: Apply local as well as global Edge Histogram Descriptor on the V Component of HSV Image and construct feature vector (fv5).

Step 6: Combine all these feature vectors in to single vector. fv = [fv1 fv2 fv3 fv4 fv5].

Step 7: Perform similarity measurement Euclidean distance, which compares query Image feature vector with each feature vector existing in the database. This measurement gives distance metrics and it shows how images in the database are similar to user input image.

Step 8: Distances are arranged in ascending order and top N images are retrieved as an output image.

IV. EXPERIMENTAL RESULTS

A. Similarity Measurement

Similarity measurement is used to measure the similarity between the query image and repository image to observe how close it is. Among the various measurement metrics, the Euclidean distance is used mostly because of its effectiveness and simplicity [27]. The minor distance between the query image feature vector and feature vector of images in the database shows that query image and resulting image are similar. We used following formula (equation 1) to calculate similarity measurement by using Euclidean distance [14] [22] [44] [27].

$$d = \sqrt{\sum_{i=1}^{k}(x_i - y_i)^2} \quad (1)$$

Where, x_i is feature vector of query image, y_i is feature vector of image belonging to the database, k is the dimension of vectors and d is the distance metrics.

B. Proposed Retrieval Structure

The overall flow diagram of the image retrieval system is seen in figure 4.

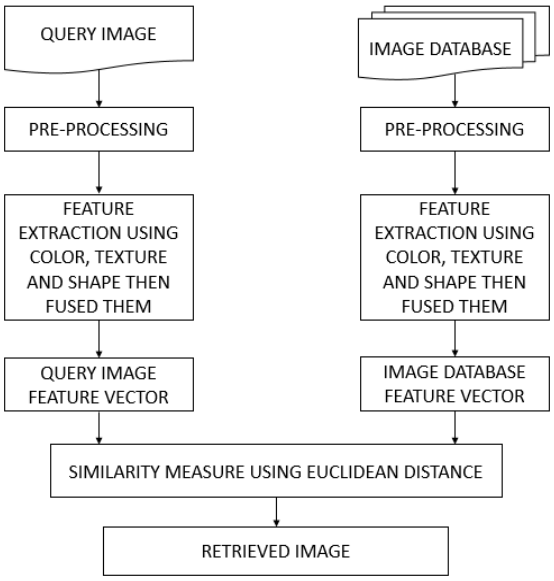


Fig. 4. Retrieval System Architecture

According to our proposed algorithm mentioned in section III – part D, The flow diagram of feature extraction is given in figure 5.

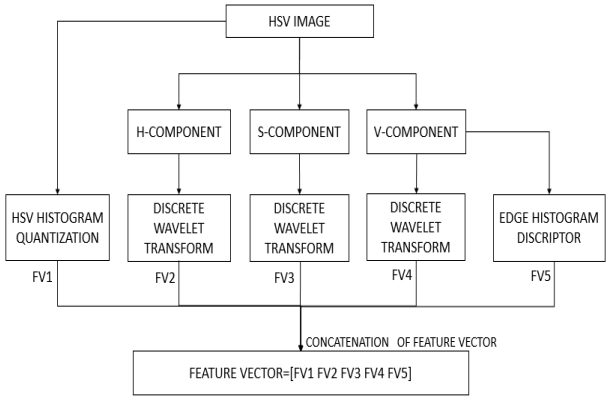


Fig. 5. Feature Extraction scheme

C. Datasets and Performance Measurement

In this paper, we used Wang image database from http://wang.ist.psu.edu/docs/related [4] [14] [15] [16]. Here, 600 images containing 6 image categories are taken from Wang database for our experimental analysis. The image categories are African, Bus, Mountain, Flower, Horses and Food. Where each category having 100 images.

The performance evaluation is an important task which is used to determine the accuracy of the retrieval system. Here, precision and recall are used to find out the accuracy of the system. The term 'Precision' exhibits the capability of the retrieval system to extract the appropriate images only [7] [19] [28]. It can be evaluated as shown in equation (2).

$$\text{Precision} = \frac{\text{Number of relevant retrieved images}}{\text{Total number of relevant images}} \quad (2)$$

The term 'Recall' exhibits the capability of system to extract the all appropriate images from the image database [19] [28]. It can be evaluated as shown in equation (3).

$$\text{Recall} = \frac{\text{Number of relevant retrieved images}}{\text{Total Number of relevant images in Database}} \quad (3)$$

D. Experimental Results

Our proposed method (using color, texture and shape based feature extraction technique) applied on 600 images of WANG image database. For result evaluation, we took 15 images randomly from each category and computed the precision and recall for each of them. Then, the average precision and average recall for each category are measured. In this paper, the top N (No. of retrieved image) images for N = 10, 20, 30, 40, 50 are extracted and the average precision is calculated for each of them (shown in Table II). Here, we found as the value of N is increased the total average precision got decreases. In table III, we calculated average recall for each value of N. The average value of precision and recall are

compared for the dissimilar value of N for this proposed methodology (shown in table II and tale III). Table IV shows Precision comparison of our proposed methodology with existing methods such as method [7] and method [13].

TABLE II. AVERAGE PRECISION

Category	Average Precision				
	N = 10	*N = 20*	*N = 30*	*N = 40*	*N = 50*
African	0.98	0.95	0.90	0.86	0.81
Bus	0.99	0.96	0.95	0.94	0.92
Flower	1	0.99	0.92	0.94	0.93
Mountain	0.91	0.85	0.80	0.74	0.70
Horses	1	0.99	0.97	0.96	0.95
Food	0.93	0.88	0.81	0.75	0.69
Total Average Precision	0.96	0.93	0.89	0.86	0.83

TABLE III. AVERAGE RECALL

Category	Average Recall				
	N = 10	*N = 20*	*N = 30*	*N = 40*	*N = 50*
African	0.04	0.20	0.27	0.34	0.40
Bus	0.04	0.19	0.28	0.37	0.46
Flower	0.05	0.20	0.27	0.37	0.46
Mountain	0.045	0.17	0.24	0.30	0.35
Horses	0.05	0.20	0.29	0.38	0.47
Food	0.046	0.17	0.24	0.30	0.34
Total Average Recall	0.048	0.18	0.26	0.34	0.41

TABLE IV. COMPARISON BASED ON AVERAGE PRECISION

Category	Method [7]	Method [13]	Proposed Method
	Avg. Precision	*Avg. Precision*	*Avg. Precision*
African	0.56	0.66	0.81
Bus	0.88	0.88	0.92
Flower	0.88	0.77	0.93
Mountain	0.51	0.55	0.70
Horses	0.77	0.77	0.95
Food	0.69	0.77	0.69
Total Average Precision	0.71	0.73	0.83

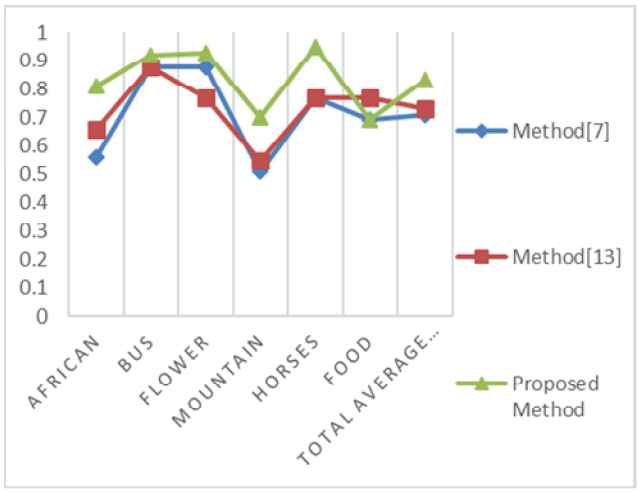
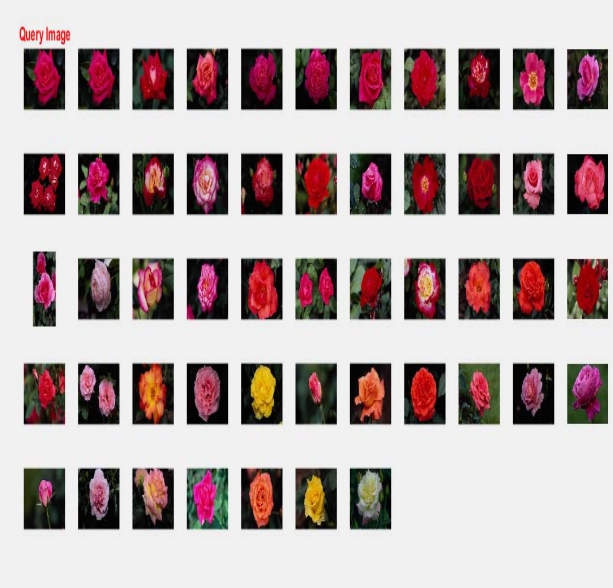


Fig. 6. Comparison graph of average precision

Figure (6) shows the comparison graph of average precision among method [7], method [13] and our proposed method.

Fig. 7. Retrieval of first 50 images corresponding to query image of Flower



V. CONCLUSION AND FUTURE SCOPE

In this work, we introduced a new combination of the pixel-level features. This proposed system is focused on color, texture as well as shape based descriptors to show an efficient retrieval system. On the basis of HSV color space, we used quantization scheme on color histogram which is more robust with the human visual framework. With this HSV histogram descriptor, we applied discrete wavelet transform on the each component of HSV image, which described the complex texture pattern in more detailed. Global as well as local edge histogram descriptor applied on the Value or Intensity component of HSV image to describe the geometric and

spatial information of edges in the image. This mixture of the color, texture and shape based techniques have increased the precision over the existing methods in the experiment with 600 images of the image database. Here, it is also observed that while decreasing the value of N (number of retrieved images), the precision value increased whereas the recall decreases. We used MATLAB R2013b for experiments. For the future perspective, the various optimization techniques such as relevance feedback, neural network, machine learning can be used to improve its retrieval efficiency.

REFERENCES

[1] Saroj A. Shambharkar, and Shubhangi C. Tirpude, "A Comparative Study on Retrieved Images by Content Based Image Retrieval System based on Binary Tree, Color, Texture and Canny Edge Detection Approach," International Conference & Workshop On Emerging Trends In Technology 2012.

[2] Manish K. Shriwas, and Prof. V.R. Raut, "Content based image retrieval: a past, present and new feature descriptor," 978-1-4799-7075-9/15/2015 IEEE

[3] N.S. Chang, and K.S. Fu, "Query by pictorial example," IEEE Trans. On Software Engineering, vol. 6, November, pp. 519-524, 1980

[4] Sumaira Muhammad, and Taha Alshaikhli, "Comparative study on Content-Based Image Retrieval (CBIR)," International Conference on Advanced Computer Science Applications and Technologies, DOI 10.1109, 2012.

[5] Dr. Ananthi Sheshasaayee, and Jasmine C., "Relevance Feedback Techniques Implemented in CBIR: Current Trends and Issues," International Journal of Engineering Trends and Technology (IJETT)/ISSN: 2231-5381/Volume 10 Number 4- Apr 2014

[6] Babita Singh, and Waseem Ahmad, "Content Based Image Retrieval: A Review Paper," International Journal Of Computer Science And Mobile Computing, Vol.3 Issue.5, PP. 769-775, May- 2014.

[7] M. Babu Rao, Dr. D. Prabhakar Rao, and Dr. A. Govardhan, "Content Based Image Retrieval System based on Dominant Color and Texture Feature," International Journal of Computer Applications, ISSN: 0975 – 8887 Volume 18- No. 6, March 2011.

[8] Aman Chadha, Sushmit Mallik, and Ravdeep Johar, "Comparative Study and Optimization of Feature-Extraction Techniques for Content based Image Retrieval," International Journal of Computer Applications, ISSN: 0975 – 8887, Volume 52– No.20, August 2012.

[9] Pranoti Mane, and N. G. Bawane,"Comparative Performance Evaluation of Edge Histogram Descriptors and Color Structure Descriptors in Content Based Image Retrieval," National Conference on Innovative Paradigms in Engineering & Technology (NCIPET-2015)

[10] Swati Agrawal, A. K. Verma, and Preetvani Singh, "Content based image retrieval using discrete wavelet transform and edge histogram descriptor," 978-1-4673-5986-3/13 ©2013 IEEE

[11] Srikanth Redrouthu, and Annapurani. K, "Time comparison of various feature extraction of content based image retrieval," International Journal of Computer Science and Information Technologies, Vol. 5 (2), PP. 2518-2523, 2014.

[12] Yogita Mistry, D.T. Ingole, and M.D. Ingole, "Efficient content based image retrieval using transform and spatial feature level fusion," 978-1-4673-9859-6/16 ©2016 IEEE

[13] Rajkumar Jain, and Punit Johari, "An improved approach of cbir using color based hsv quantization and shape based edge detection algorithm," 978-1-5090-0774-5/16 ©2016 IEEE

[14] F. Long, H. Zhang, H. Dagan, and D. Feng, "Fundamentals of content based image retrieval," Multimedia Signal Processing Book, Chapter 1, Springer-Verlag, Berlin Heidelberg New York, 2003.

[15] Nikita Upadhyaya, and Manish Dixit, "A Review: Relating Low Level Features to High Level Semantics in CBIR," International Journal of Signal Processing, Image Processing and Pattern Recognition" vol. 9, No. 3(2016), pp. 433-444 (2016).

[16] Neelima Bagri, and Punit Kumar Johari, "A Comparative Study on Feature Extraction using Texture and Shape for Content Based Image Retrieval," International Journal of Advanced Science and Technology vol. 80, ISSN: 2005-4238, pp. 41-52, 2015

[17] P. Hiremath, and J. Pujari, "Content Based Image Retrieval using Color, Texture and Shape features," 15th International Conference on Advanced Computing and Communications, 2007.

[18] Prashant Shrivastava, Om Prakash, and Ashish Khare, "Content--based image retrieval using moments of wavelet transform," 978-1-4799-7204-3/14©2013 IEEE

[19] Garima Gupta, and Manish Dixit, "CBIR on Biometric Application using Hough Transform with DCD, DWT Features and SVM Classification," International Journal of Engineering and Innovative Technology, ISSN: 2277-3754 , Volume 4, Issue 12, June 2016.

[20] M. Kokare, P. K. Biswas, and B. N. Chatterji, "Texture image retrieval using rotated wavelet filters," Pattern Recogn. Lett., vol. 28, pp. 1240-1249, 2007.

[21] A. Anandh, Dr. K.Mala, and S.sauganya, "Content based image retrieval system based on semantic information using color, texture and shape feature," 978-1-4673-8437-7/16/©2013 IEEE

[22] A. Haris Rangkuti, Nashrul Hakiem, Rizal Broer Bahaweres, Agus Harjoko, and Agfianto Eko Putro, "Analysis of image similarity with cbir concept using wavelet transform and threshold algorithm," 978-1-4799-0210-1/13©2013 IEEE

[23] Peng Wu, Yong Man Ro, Chee Sun Won, and Yang Lim Choi, "Texture Descriptors in MPEG-7," Computer analysis of Images and Patterns, vol. 2124, pp 21-28, August 2001

[24] C.S. Won, D.K. Park, and S.J. Park, "Efficient use of Edge Histogram Descriptor-An Overview," ETRI Journal, vol. 24, Number 1, Feb 2002, pp. 23-30.

[25] Dong Kwon Park, Yoon Seok Jeon, and Chee Sun Won, " Efficient use of Local Edge Histogram Descriptor," ACM workshop on multimedia, November 2000, pp. 51-55

[26] R. Datta, J. Li, and J. Wang, "Content-Based Image Retrieval - Approaches and Trends of the new Age," ACM Computing Survey, Vol. 40, no. 2, pp. 1-60, April 2008.

[27] Sawat Somnugpong, and Kanokwan Khiewwan, "Content- based image retrieval using a combination of color correlograms and edge direction histogram," 978-1-5050-2033-1/16/©2016 IEEE

[28] Nikita Upadhyaya, and Manish Dixit, "An Insight to Various CBIR Technique: A Survey," International Journal of Advanced Research in Computer Science and Software Engineering, Volume 6, Issue 5, May 2016, ISSN: 2277 128X

[29] Ruchi Jayaswal, and Jaimala Jha, "A hybrid approach for image retrieval using visual descriptors," unpublished.