6. Image Retrieval

6.1 Introduction

The chapter deals with image features, characteristics of image databases used and proposed methods for image retrieval. The image retrieval has been carried out on the basis of:

- Color codes of entire image
- Foreground color codes
- Foreground shape correlation
- Combination of foreground color codes and shape correlation
  - With selectable percentage proportion of weight of foreground color codes and foreground shape correlation for composite similarity measure
- Similar face – images containing complex background

The performance of retrieval methods has been evaluated with Precision, Recall, F – measure and P – R curves for various images of different classes and categories. Query responses of some example-images have also been presented. The method and results of face extraction and similar-face-image retrieval are covered lastly in the chapter.

The retrieval of similar images needs to meet two extreme requirements – (i) Retrieve only similar images and (ii) Retrieve as many as possible similar images. The performance indicator for the first requirement is Precision whereas that of the second is Recall. (Section 3.3). An attempt to improve Precision by either incorporating stringent features or strict image similarity comparison-measures for excluding dissimilar images ends up in exclusion of similar images as well, adversely affecting the Recall. On other hand, an attempt to increase the number of retrieved similar images leading to improvement in Recall by incorporating broader features or relaxed similarity-measures ends up in retrieving more number of similar images along with dissimilar images, adversely affecting Precision. Thus a 'good' CBIR system should retain maximum possible Precision for higher Recall for large image databases consisting of variety of images. Section 2.8 - Our Observations and Section 2.9 - Our Approaches for image retrieval may be referred for details.

The proposed methods for image retrieval are based on two streams of techniques. The first stream follows broader image descriptors – Color codes and corresponding histograms. Whereas, the second stream follows reliable processing leading to precise detection of prominent boundaries eventually revealing foreground. Image retrieval based on whole image comparison has been carried out with broader image descriptors for retrieving images having similar color code distribution. The other methods are based on foreground of the images. The extracted foreground has been utilized for comparison of objects contained in it. The correlation coefficients have been used as similarity comparison-measure for matching shape of the foregrounds. The other three methodologies combine aforesaid two streams of techniques for image retrieval. The first combinational technique is based on similarity comparison of foreground color codes. The second combinational technique is based on color-codes and shape of the foreground with selectable proportion of weight of shape & color-code in composite similarity-measure. And the third one is the combinational technique applied for application specific CBIR for similar-face image retrieval.

Thus, our approaches for image retrieval techniques exploits reliable processing resulting precise features for better Precision and broader image features for better Recall. *The methods are novel for the extracted features and their use for image retrieval.*

6.2 Image Features

Figure 47 shows the block diagram for extraction of features for the developed CBIR system. Parameters given as input includes selected image name for single image processing or folder name for bulk processing and wavelet decomposition level.

The extraction of image features can be carried out either for one image or for all images stored in a folder for supporting addition of an image into existing image database and to facilitate bulk processing respectively. The color code features of image can be separately extracted. The option of extracting all features take out all features - prominent boundaries based and color code based. The extracted features stored in appropriate data structures are preserved in secondary storage as a file corresponding to the image. The unknown dimension of various extracted features (i.e.

number of contours, number of vertices in contours) and their processing enforced exhaustive applications of programming-skills & utilization of Matlab-features.

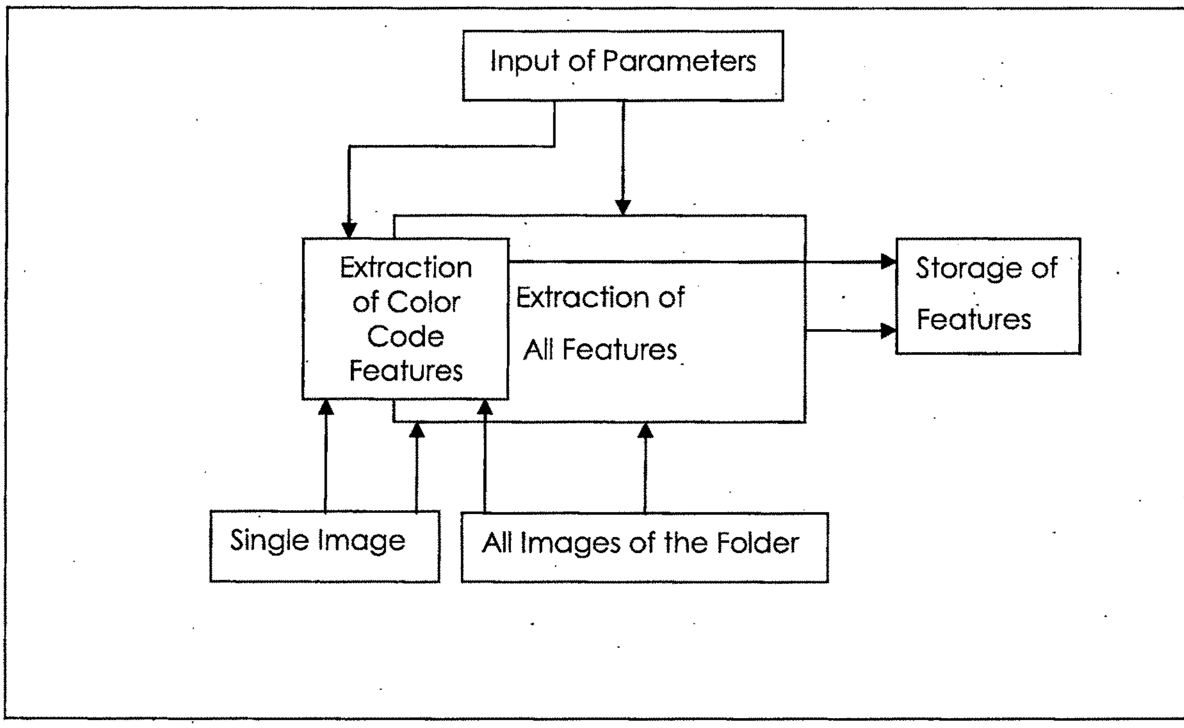


Figure 47. Block diagram - Feature extraction.

The extracted image features listed in Table 5, can be categorized as

- Image attributes – Name (Path), type & dimension.
- Color features - Color codes, Histograms
- Boundaries based features - Regional attributes , edges
- Foreground related attributes – boundaries based and color features for foreground
- Face region features

Table 5. Extracted features.

Sr. No.	Features
1	Path of the image.
2	No of rows of the image.
3	No of column of the image.
4	Image type.
5	Normalized global histogram of the image. For R G and B channels. Not utilized at present.
6	Normalized cumulative global histogram of the image. For R G and B channels. Not utilized at present.
7	Color codes.
8	Normalized histogram of color codes.
9	Normalized cumulative Histogram of color codes. Not utilized at present.
10	Thinned edges.
11	Foreground regions of the image.
12	Background regions of the image.
13	Watershed pixels.
14	Composite prominence measure.
15	Labeled regions.
16	Labeled regions converted to RGB image.
17	Image category. Presently describing 'face' or 'unknown'.
18	Extracted face.
19	Regions corresponding to color codes of whole image.
20	Sorted histogram of color codes of whole image.
21	Regions indices, sorted for region area. Regions are found following prominent boundary based approach.
22	Regional attributes for regions of whole image. Area, Centroid, Bounding box, Extrema, Extent, Solidity (given by Area/ConvexArea), Eccentricity, Convex hull, Minor axis length, Major axis length, orientation.
23	Normalized Un-segmented foreground region of the image.
24	Un-segmented foreground of the image.

Table 5 (Contd.). Extracted features.

Sr. No.	Features
25	Normalized global histogram of foreground of the image. For R G and B channels. Not utilized at present.
26	Normalized cumulative global histogram of foreground of the image. For R G and B channels. Not utilized at present.
27	Color codes for foreground.
28	Normalized histogram of color codes of foreground.
29	Normalized cumulative Histogram of color codes of foreground. Not utilized at present.
30	Regions corresponding to color codes of foreground.
31	Sorted histogram of color codes of foreground.
32	Ratio of two axes of Extrema corresponding to normalized face region. Not utilized at present.
33	Ratio of other two axes of Extrema corresponding to normalized face region. Not utilized at present.
34	Ratio of Minor axis length to Major axis length of the ellipse that has same normalized second central moments as the face region.
35	Orientation of face region. Angle in degree between x-axis and the major axis of the ellipse that has same second moments as the face region.
36	Average of foreground region color code.
37	Ratio of foreground area to image area indicating percentage contribution of foreground region in the image.
38	Two additional extra feature fields Incorporated for future needs.

The color codes are used to describe color attribute of pixels of images. A color code represents a set of colors of RGB color space. Total of 27 color codes are used to represent entire range of RGB color space. The pixels assigned with color codes effectively segments the image by forming regions consisting of pixels with same color - codes. Figure 48 and Figure 49 (a) illustrate the color codes assigned to pixels resulting into segmentation of image. The labeled regions of identical color (same color – codes) are shown with same color in the segmented images. Figure 49 (b) Left is a separated region of colors corresponding to flowers whereas Figure 49 (b) Right is for the regions corresponding to green leaves.

Refer Annexure 4, Section A-4.4 for details of proposed novel color codes and results of segmentation applied on images of standard databases of BSDB [Fowlkes, on line] [Martin, 2001] and SIMPLIcity [Wang, 2001].

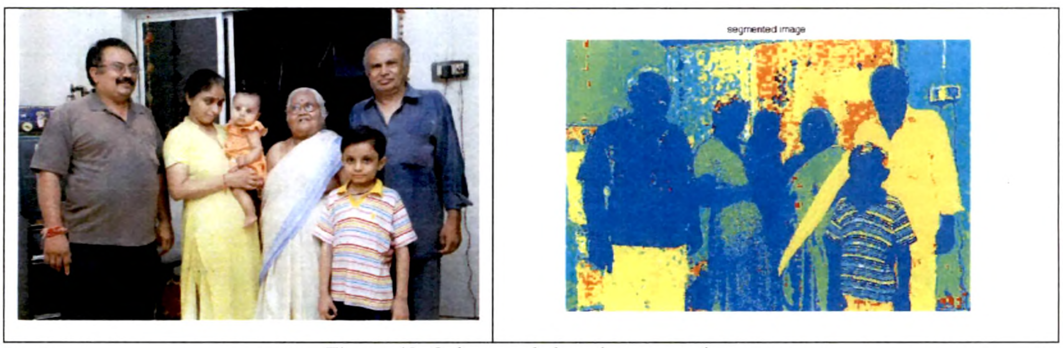


Figure 48. Color – code based segmentation.

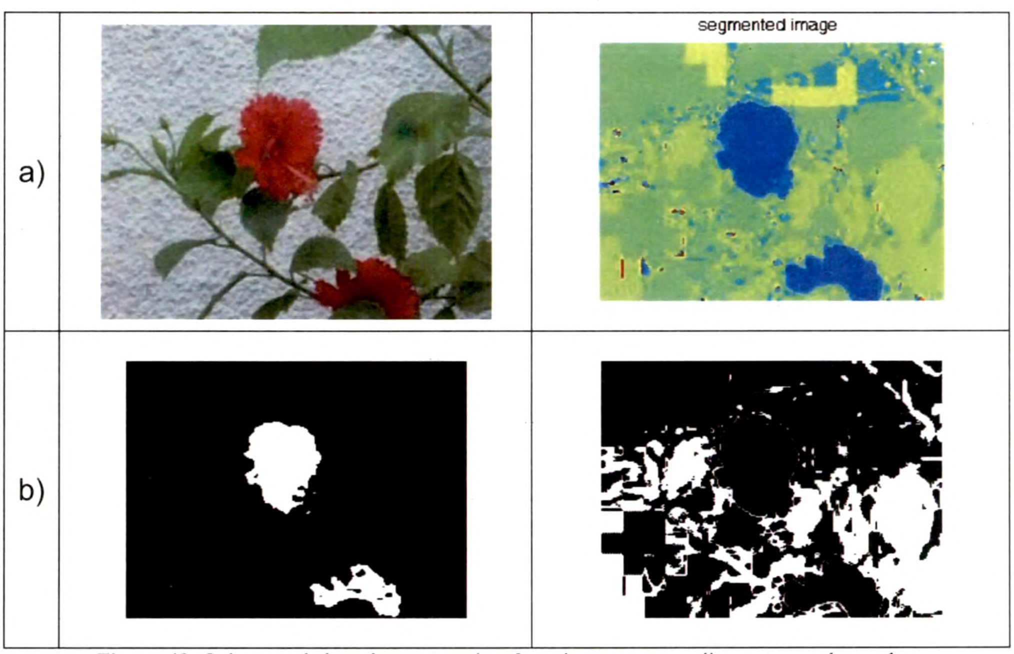


Figure 49. Color – code based segmentation & regions corresponding to two color-codes.

6.3 SIMPLIcity Image Database [Wang, 2001] [SIMPLIcity, on line] - Classes & Characteristics

The dataset consists of total 1000 images of 10 classes and 100 images per class. Images are of medium resolutions and reasonable size. The test set has used by many researchers for the purpose of CBIR. Table 6 describes characteristics of image classes.

Table 6. SIMPLIcity Image Database [Wang, 2001] [SIMPLIcity, on line] - Classes and Characteristics

Sr. No.	Class Name	Characteristics	Sample Images
0	Tribal people	Single or group of tribal-inhabitants in different poses with different backgrounds; Colored faces; typical tribal-dressing;	
1	Seashore	Sea, sand, sky with clouds; sea-shore objects; Images cover distant objects;	
2	Sculpture	Majority of sculpture images captured as distant objects having sky as background;	
3	Bus	Mostly single bus, covering major portion of images; Differently colored various types of buses with different backgrounds.	
4	Dinosaur	Different types of dinosaurs with non-textured multi-colored backgrounds;	
5	Elephant	Single or multiple elephants in different backgrounds;	
6	Flower	Different types and colored flowers covering major portion of images;	
7	Horse	Single or multiple horses in different backgrounds;	
8	Mountain	Mountains and sky	
9	Served Food on Restaurant-table	Typical images of different types of served food on restaurant-tables;	

6.4 ALOI Image Database [ALOI, on line] [Geusebroek, 2001]

Amsterdam Library of Object Images (ALOI) provides a collection of color images of one-thousand small objects, recorded for scientific purposes. Over one hundred images per object were captured systematically in controlled conditions for varied viewing angles, illumination angles and illumination colors for the sensory variation in object recordings. The images were captured by one of five lights turned on for 15 different illumination angles, 12 different illumination color configuration and 72 object view point variations. Produced smooth variations in intensity and shadows in different directions and parts of wide variety of objects offer a comprehensive test set for studying segmentation and feature extraction issues. Figure 50 shows few sample-images of an object recorded with such variations.

The test set consisting of some of the images of ALOI [ALOI, on line] [Geusebroek, 2001] database has been used as one of the databases for image retrieval techniques for studying effects of aforesaid variations on foreground shape and foreground color codes.

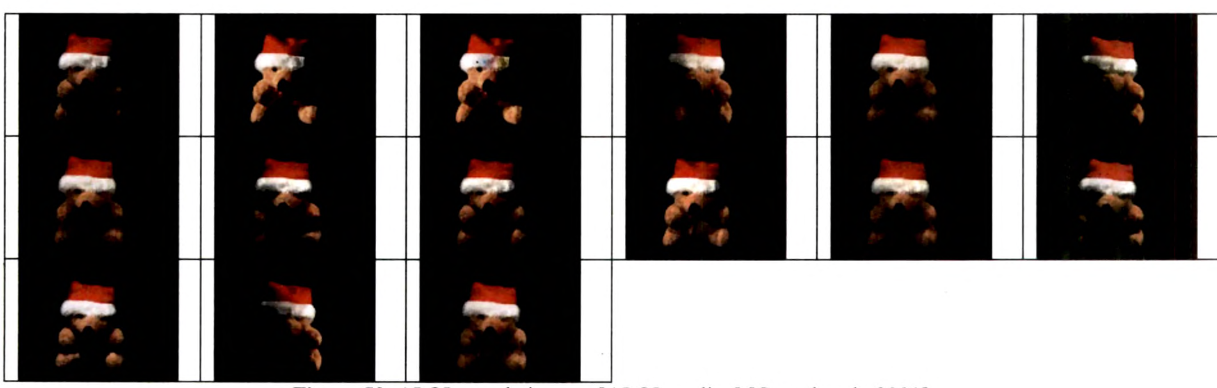


Figure 50. ALOI sample images [ALOI, on line] [Geusebroek, 2001].

6.5 Proposed Techniques

The proposed techniques, based on Color codes of entire image, Foreground color codes, Foreground shape correlation and Combination of foreground color codes & shape correlation follow steps mentioned below for image retrieval. Like all CBIR techniques, incorporated image features and method for computation of similarity measures differentiate methods and their respective performances for retrieval of images. The proposed methods consist of three phases – (i) Input reading (ii) method specific image-feature reading & processing for similarity measures and (iii) output / presentation. The method-specific Step 3 and Step 4 are presented in respective sections of proposed methods. The generic steps for proposed methods are:

Step 1: Read - name of selected query image, name of selected target folder. and image to be searched for. Perform validations for inputs.

Step 2: Read names of files containing all image features.

Step 3: *Read (or extract) required image-features for the query image.*

Step 4: *For every image-feature-file of target folder,*

Read corresponding image-features of the image-feature-file of target folder

Calculate (dis)similarity_index $_i$ for i th image of the database.

Preserve path of data base image, needed for display.

Step 5: Read similarity cut-off.

Step 6: Sort calculated (dis)similarity indices in descending order.

Step 7: Count no of images having better similarity index than the similarity cut-off. Prepare for proper presentation of results.

Step 8: Display all similar images having better similarity index than the similarity cut-off, in order of decreasing similarity (from left to right, row wise).

Algorithm 4. Generic steps for proposed image retrieval methods

The GUI (Annexure 2) based developed CBIR system runs on a stand-alone machine. The database can be expanded by adding images into any folder which can be processed subsequently for feature extraction at once with a mouse click. In absence of indexing mechanism, features are stored in files. A user will be prompted to carry out feature extraction of a query image, if not done earlier with help of the GUI for that single image. The preprocessing of a query image is adopted by considering the high time complexity of algorithms and repetition in the experimentations. For real time deployment of the system, query preprocessing can be eliminated.

Similarity cut-off selection is to be carried out by user with GUI. Lower similarity cut-off signifies higher permitted dissimilarity in the retrieved images.

The image-query response gets presented in a Matlab Figure-window containing a grid of 4 x 4 thumbnail-images along with their storage path.

6.6 Whole Image Color Codes Based CBIR

The proposed method for image retrieval enables user to perform search on the basis of color attributes of entire image. The color code assigned to a pixel is designated for broadly describing the color of pixel. Being a broader descriptor, a color code can accommodate pixel color variations without affecting corresponding color feature. The proposed technique compares normalized global histogram of color codes constructed for entire query image with that of images of the database for measuring color distribution similarity. The steps involved in reading of image features, their processing and computation of similarity index are shown below. These method specific steps replace corresponding generic Steps 3 & 4 of Algorithm 4, Section 6.5.

The method specific steps are:

Step 3: Read (extract) whole image color code features of given query image.

Step 4: For every image-feature-file of target folder,

Read corresponding whole image color code features of the image-feature-file of target folder.

Calculate (dis)similarity_index $_i$ = $\sum abs(h_{qj} - h_{ij})$, for $1 < j <=$ number of bins,

Where,

h_{qj} indicates j th bin of normalized histogram of color codes for the query image.

h_{ij} indicates j th bin of normalized histogram of color codes for i th image of database .

Preserve path of data base image, needed for display.

Algorithm 5. Whole image color codes based image retrieval.

6.6.1 Performance Evaluation

The performance of the method has been tested on image database of SIMPLIcity [Wang, 2001] [SIMPLIcity, on line] consisting of 1000 images. Exhaustive performance evaluation has been carried out for four classes of database – Bus, Horse, flower and dinosaur. Recall, Precision and F –measure are computed for sample queries of each class of images. The performance measures for different similarity cut-offs have been tabulated for comparison. Average Recall, Average Precision and Average F – measures for the class are tabulated and plotted along with P – R curves for query responses.

6.6.1.1 Query Image Class: Bus

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 1000 images has been shown in Table 7 for
  - 11 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs &

- 56 queries
- The selected query images possess variations in object-poses, number of foreground objects, object-colors, backgrounds and illumination conditions.

Table 7. Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Bus.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
300.jpg 	25	53	82	100	0.53	0.64	0.58
	30	45	65		0.45	0.69	0.54
	40	25	31		0.25	0.81	0.38
	50	13	16		0.13	0.81	0.22
	60	4	6		0.04	0.66	0.08
	70	1	1		0.01	1.00	0.02
310.jpg 	25	55	70	100	0.55	0.79	0.65
	30	46	54		0.46	0.85	0.60
	40	30	33		0.3	0.91	0.45
	50	19	19		0.19	1.00	0.32
	60	7	7		0.07	1.00	0.13
358.jpg 	25	68	99	100	0.68	0.69	0.68
	30	60	75		0.6	0.8	0.69
	40	31	37		0.31	0.84	0.45
	50	17	18		0.17	0.94	0.29
	60	7	7		0.07	1.00	0.13
315.jpg 	25	33	105	100	0.33	0.31	0.32
	30	27	80		0.27	0.34	0.30
	40	13	35		0.13	0.37	0.19
	50	6	14		0.06	0.43	0.11
	60	3	5		0.03	0.6	0.06
319.jpg 	25	32	72	100	0.32	0.44	0.37
	30	24	51		0.24	0.47	0.32
	40	15	26		0.15	0.58	0.24
	50	6	10		0.06	0.6	0.11
	60	2	2		0.02	1.00	0.04
326.jpg 	25	27	184	100	0.27	0.14	0.18
	30	22	140		0.22	0.15	0.18
	40	9	61		0.09	0.15	0.11
	50	5	23		0.05	0.21	0.08
	60	1	7		0.01	0.14	0.02

Table 7 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Bus.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
365.jpg 	25	60	174		0.60	0.34	0.43
	30	52	132		0.52	0.40	0.45
	40	35	68	100	0.35	0.51	0.42
	50	11	18		0.11	0.61	0.19
	60	5	8		0.05	0.63	0.09
388.jpg 	25	62	101		0.62	0.61	0.61
	30	50	78		0.50	0.61	0.55
	40	33	46	100	0.33	0.71	0.45
	50	11	17		0.11	0.65	0.19
	60	8	9		0.08	0.89	0.15
366.jpg 	25	26	187		0.26	0.13	0.17
	30	19	145		0.19	0.13	0.15
	40	8	88	100	0.08	0.09	0.08
	50	5	47		0.05	0.10	0.07
	60	5	15		0.05	0.33	0.09
344.jpg 	25	43	54		0.43	0.80	0.56
	30	37	41		0.37	0.90	0.52
	40	23	23	100	0.23	1.00	0.37
	50	15	15		0.15	1.00	0.26
	60	5	5		0.05	1.00	0.10
369.jpg 	25	48	138		0.48	0.35	0.40
	30	40	102		0.40	0.39	0.39
	40	20	46	100	0.20	0.43	0.27
	50	8	13		0.08	0.62	0.14
	60	4	5		0.04	0.80	0.08

The average Recall and average Precision for the query image class bus for different similarity cut-offs have been tabulated in Table 8. Corresponding P – R curves of sample queries of the table along with average Precision & average Recall are shown in Figure 51. Average Precision, average Recall and average F-measures for different similarity cut-offs for the query images of Table 8 has been plotted in Figure 52.

Table 8. Average Recall, Average Precision & Average F -measure. (Whole image color codes). Class – Bus.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.46	0.48	0.47
30	0.38	0.52	0.44
40	0.22	0.58	0.32
50	0.11	0.63	0.18
60	0.05	0.73	0.09
70	0.01	1.00	0.02

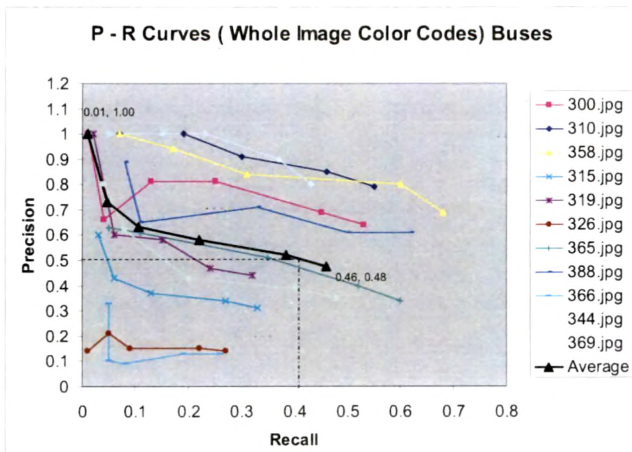


Figure 51. P- R curves (whole image color codes). Class - Bus.

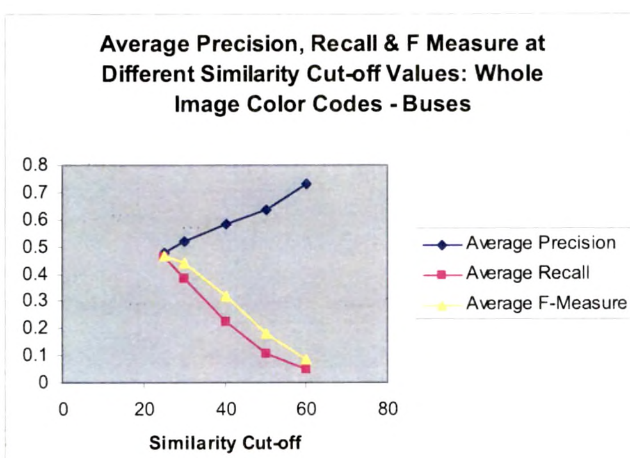


Figure 52. Average Precision, Average Recall, Average F – measures verses Similarity cut-offs. (Whole image color codes). Class – Bus.

Following points are observed:

- The nature of obtained P – R curves matches with the practical P – R curves.
- Stricter similarity cut-off increases the Precision at the cost of Recall.

- Despite vast variations in bus colors, background, poses and illumination conditions, high recall with good precision is achievable for many sample queries.
- For many queries, Precision of 1.0 is achieved.
- The Precision and recall are poor for query images having orange / yellow colored buses as other image-classes contain images of similar color distribution.
- Range of average performance measures for the class
  - 100 % of average Precision for 1 % of average Recall
  - 48 % of average Precision for 46 % of average Recall
  - Giving 52 % of fall in average Precision to raise average Recall by 45 %
- The value of average Recall at average Precision of 0.5 is 0.41 – a reasonably good performance measures.
- Increase in the user selected similarity cut-off indicates higher threshold for the similarity measures for retrieving very similar images. As a result, average Recall falls down due to elimination of images having lesser similarity and average Precision increases as retrieved images are very similar due to higher cut-off resembling Precision – Recall behavior of any practical CBIR system.

6.6.1.2 Query Image Response Examples: Class – Bus

The query responses of a bus image [Wang, 2001] [SIMPLIcity, on line] at two different similarity cut-offs have been shown in Figure 53 and Figure 54.

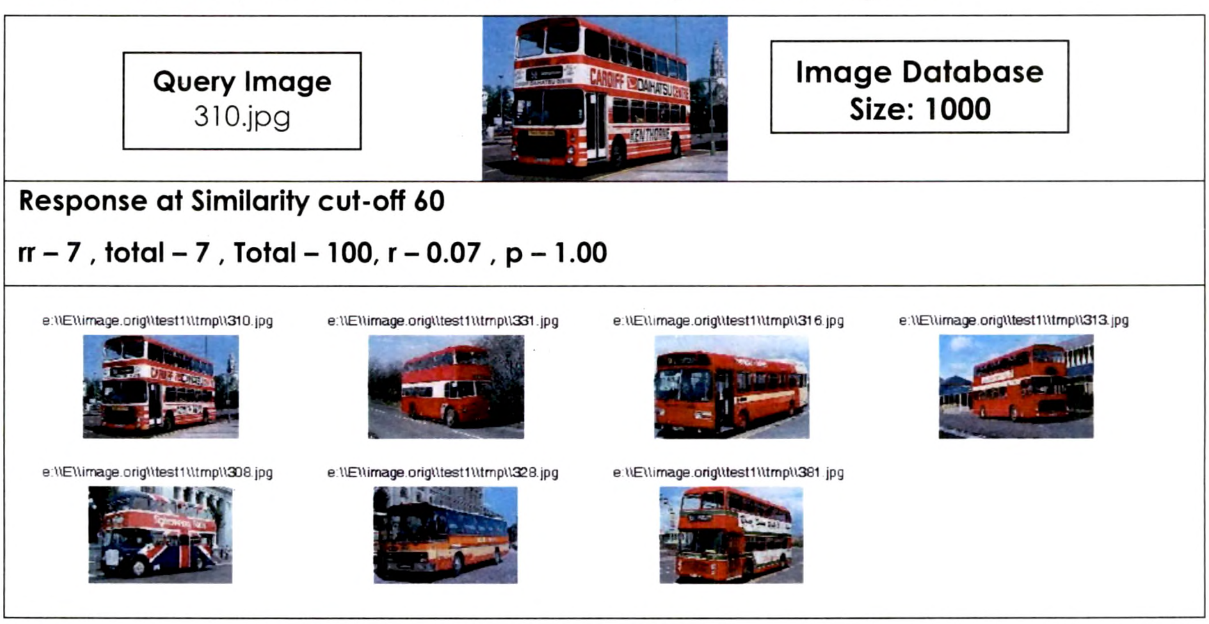


Figure 53. Query response of a bus image at similarity cut-off 60.

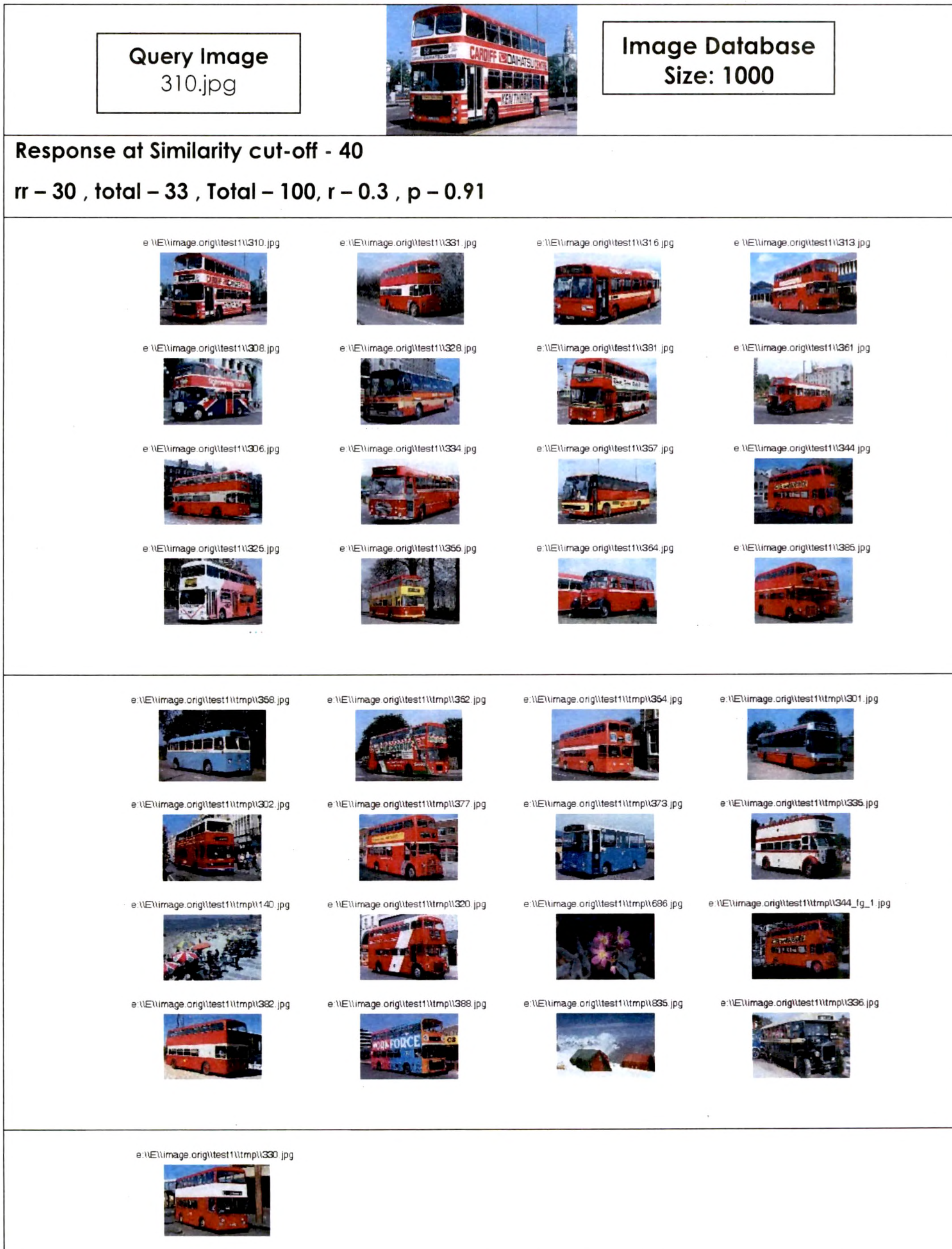


Figure 54. Query response of a bus image at similarity cut-off 40.

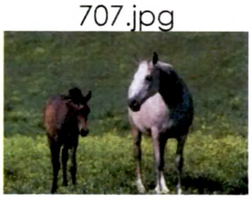
6.6.1.3 Query Image Class: Horse

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 1000 images has been shown in Table 9 for
  - 6 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs &
  - 29 queries
- The selected query images possess variations in object-poses, number of foreground objects, object-colors, backgrounds and illumination conditions.
- The foreground objects constitute relatively lesser percentage-portion of the image compared to image class bus.
- Relatively less variations in the background color distributions among images of the class.

Table 9. Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Horse.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
700.jpg 	25	53	92	100	0.53	0.57	0.55
	30	51	81		0.51	0.63	0.56
	40	34	56		0.34	0.61	0.44
	50	17	27		0.17	0.63	0.27
	60	7	13		0.07	0.54	0.12
	70	3	5		0.03	0.6	0.06
725.jpg 	25	71	96	100	0.71	0.74	0.72
	30	69	93		0.69	0.74	0.72
	40	61	73		0.61	0.84	0.71
	50	48	54		0.48	0.89	0.62
	60	27	36		0.27	0.75	0.40
	70	13	15		0.13	0.87	0.23
744.jpg 	25	33	53	100	0.33	0.62	0.43
	30	26	42		0.26	0.62	0.37
	40	14	21		0.14	0.67	0.23
	50	7	11		0.07	0.64	0.13

Table 9 (Contd). Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Horse.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
757.jpg 	25	70	78	100	0.7	0.90	0.79
	30	68	73		0.68	0.93	0.79
	40	54	57		0.54	0.95	0.69
	50	41	41		0.41	1	0.58
	60	23	23		0.23	1	0.37
701.jpg 	25	81	95	100	0.81	0.85	0.83
	30	76	86		0.76	0.88	0.82
	40	65	70		0.65	0.93	0.76
	50	54	55		0.54	0.98	0.70
	60	33	34		0.33	0.97	0.49
	70	14	14		0.14	1.00	0.25
707.jpg 	25	78	91	100	0.78	0.86	0.82
	30	73	83		0.73	1.00	0.84
	40	59	66		0.59	0.89	0.71
	50	46	49		0.46	0.94	0.62
	60	37	37		0.37	1.00	0.54
	70	23	23		0.23	1.00	0.37

The average Recall and average Precision for the query image class horse for different similarity cut-offs has been tabulated in Table 10. The P – R curves for sample queries of the table and corresponding average Precision & average Recall are shown in Figure 55. Average Precision, average Recall and average F-measures for different similarity cut-offs for the query images of Table 10 have been plotted in Figure 56.

Table 10. Average Recall, Average Precision & Average F - measure. (Whole image color codes). Class – Horse.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.55	0.76	0.64
30	0.52	0.80	0.63
40	0.41	0.81	0.55
50	0.30	0.85	0.45
60	0.25	0.85	0.39
70	0.13	0.87	0.23

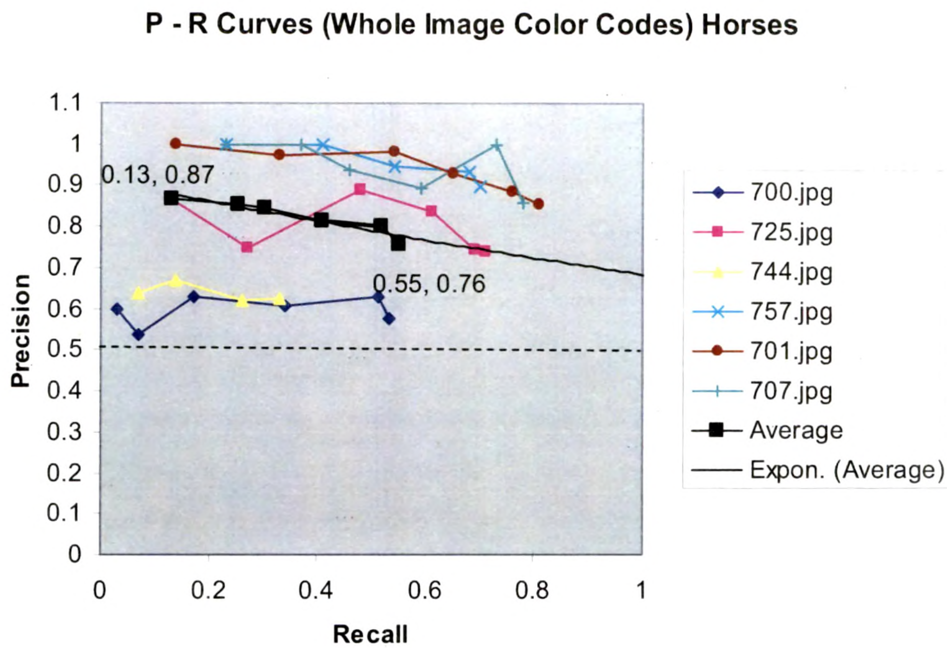


Figure 55. P- R curves (whole image color codes). Class- Horse.

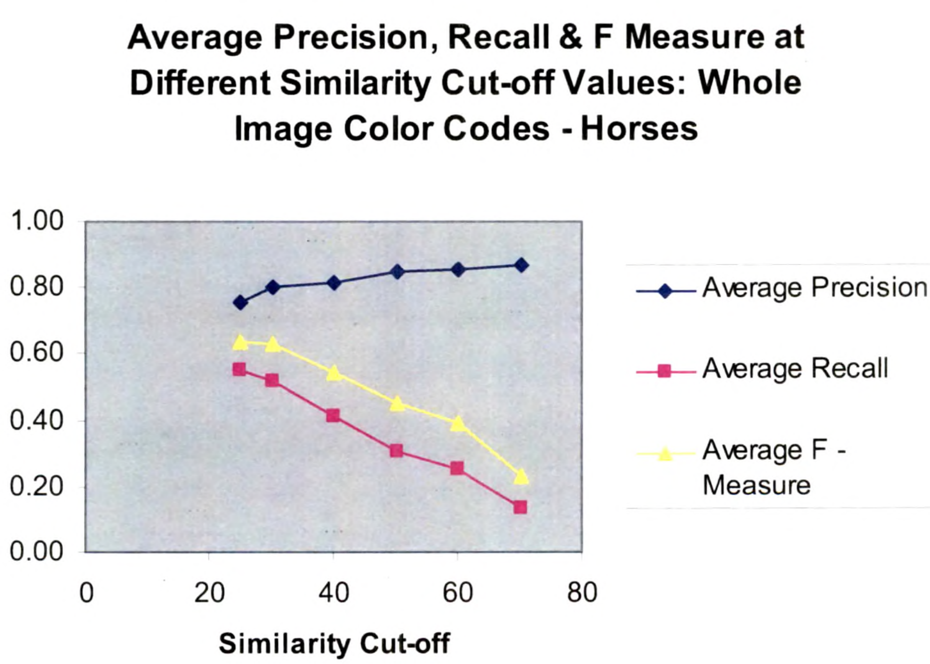


Figure 56. Average Precision, Average Recall, Average F – measures verses Similarity cut-offs. (Whole image color codes). Class – Horse.

Following points are observed:

- The nature of obtained P – R curves is close to ideal P – R curves for some of the query images.
- For the variations in colors & poses of foreground objects, background and illumination conditions, high recall with good precision is achievable for many sample queries.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- For many queries, Precision of 1.0 is achieved.
- For many queries, Recall greater than of 0.7 is achieved.
- The uniqueness of the background colors combined with foreground colors ends up with color distributions not common in the images of other classes giving very good performance measures.
- Range of average performance measures for the class
    - 87 % of average Precision for 13 % of average Recall
    - 76 % of average Precision for 55 % of average Recall
    - Giving only 11 % of fall in average Precision to raise average Recall by 42%.
- The exponentially extended trend line is well above Precision = (0.5) line and does not intersect average Recall till its maximum possible value, implies more than 50% of average Precision for all average Recall values indicating exceptionally good performance measures.

6.6.1.4 Query Image Response Examples: Class - Horse

The query response of a horse image [Wang, 2001] [SIMPLIcity, on line] at similarity cut-off 25 has been shown in Figure 57. The Recall of 71% with Precision of 73% at similarity cut-off of 25 is remarkable, giving 0.72 as F-measure. The query response of another image consisting of two horses has been shown in Figure 58 giving 100 % precision with Recall of 14%.

Figure 57. Query response of a horse image at similarity cut-off 25.

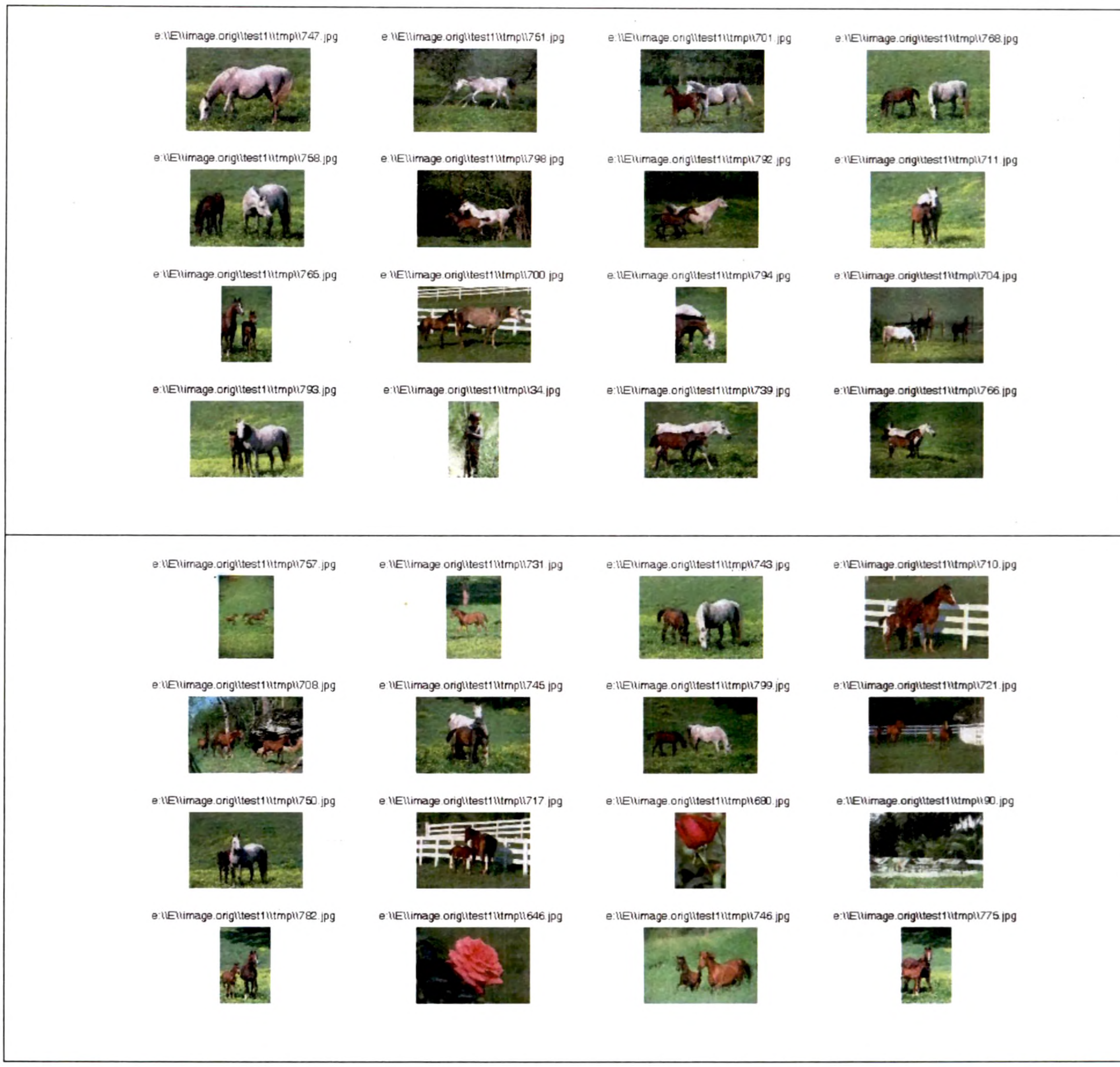


Figure 57 (Contd.). Query response of a horse image at similarity cut-off 25.

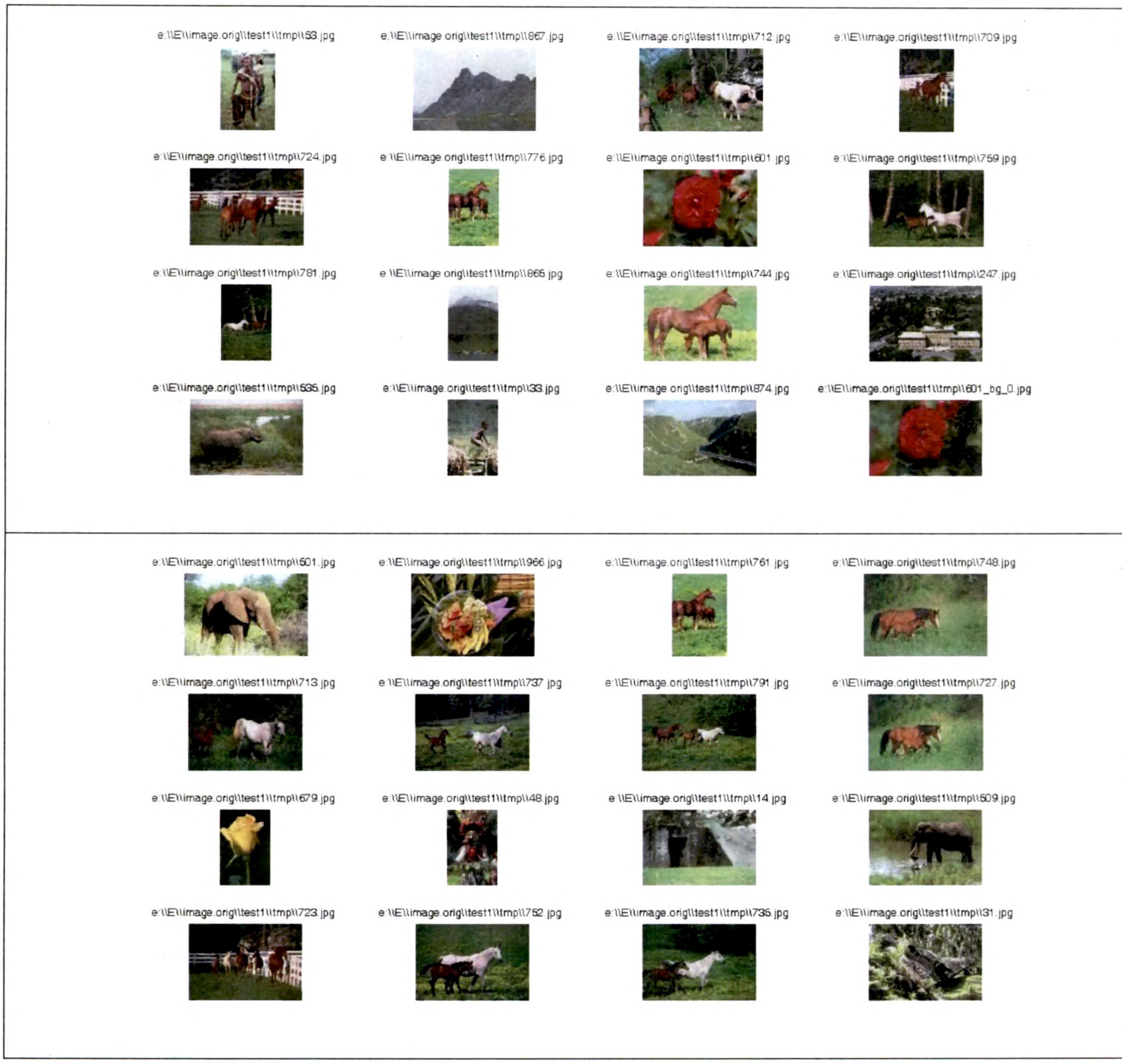


Figure 57 (Contd.). Query response of a horse image at similarity cut-off 25.

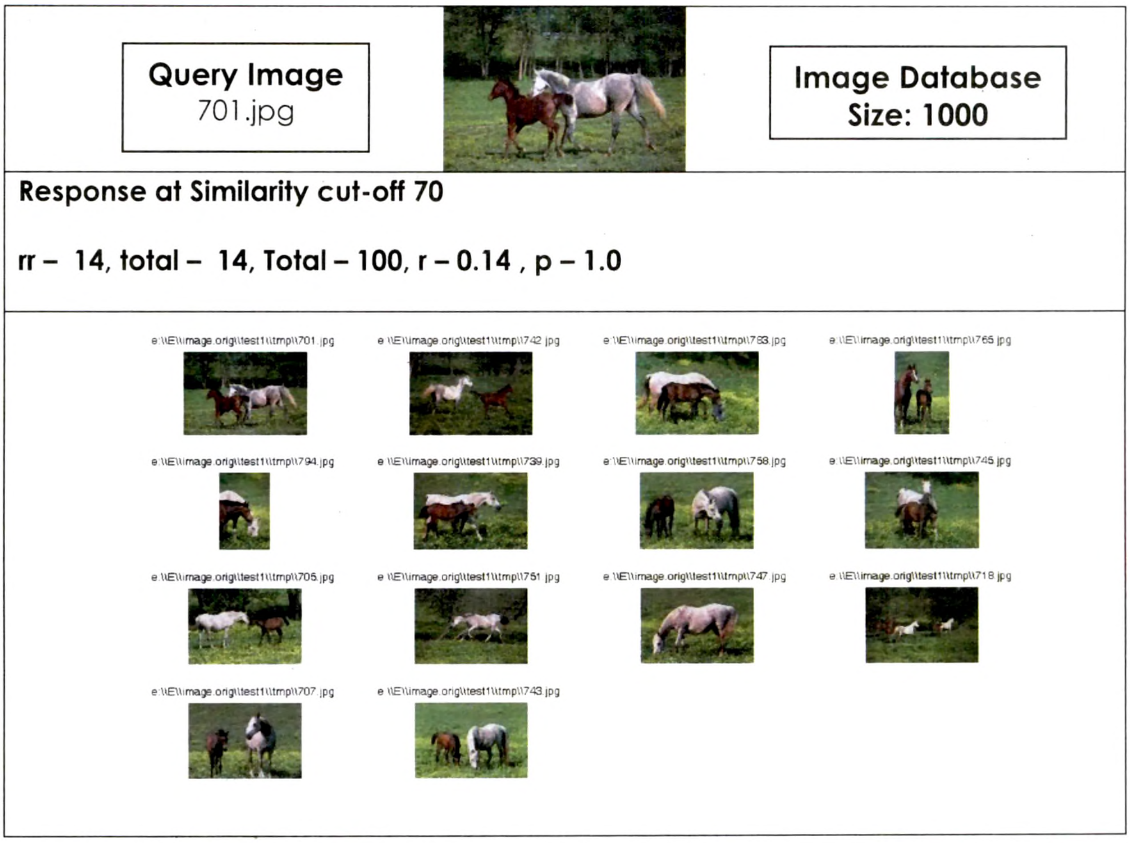


Figure 58. Query response of another horse image at similarity cut-off 70.

6.6.1.5 Query Image Class - Flower

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 1000 images has been shown in Table 11 for
    - 10 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs
    - 44 queries
- The selected query images possess variations in object-poses, number of foreground objects, object-colors, backgrounds and illumination conditions.
- The foreground objects generally constitute significant portion of the image.

Table 11. Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Flower.

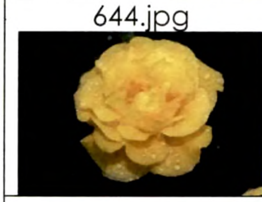
Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
602.jpg 	25	21	28	57	0.37	0.75	0.49
	30	16	21		0.28	0.76	0.41
	40	13	14		0.23	0.93	0.37
	50	9	9		0.16	1	0.27
	60	3	3		0.05	1	0.10
606.jpg 	25	34	43	57	0.60	0.79	0.68
	30	29	31		0.51	0.94	0.66
	40	17	18		0.31	0.94	0.45
	50	9	9		0.16	1	0.27
	60	2	2		0.03	1	0.07
644.jpg 							
	40	14	20	24	0.58	0.7	0.64
	50	13	15		0.54	0.87	0.67
	60	5	5		0.21	1	0.34
655.jpg 							
	40	17	21	57	0.30	0.81	0.44
	50	8	8		0.14	1	0.25
	60	3	3		0.05	1	0.10
656.jpg 	25	4	6	9	0.44	0.67	0.53
	30	4	4		0.44	1	0.62
	40	1	1		0.11	1	0.20
	50	1	1		0.11	1	0.20
	60	1	1		0.11	1	0.20

Table 11 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class - Flower.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/p + 1/r)
696.jpg 	25	4	4	57	0.07	1	0.13
	30	3	3		0.05	1	0.10
	40	3	3		0.05	1	0.10
	50	2	2		0.03	1	0.07
	60	1	1		0.02	1	0.03
675.jpg 	40	14	18	24	0.58	0.78	0.67
	50	6	6		0.25	1	0.40
	60	2	2		0.08	1	0.15
682.jpg 	25	9	24	57	0.15	0.38	0.22
	30	5	18		0.09	0.28	0.13
	40	4	11		0.07	0.36	0.12
	50	2	7		0.03	0.29	0.06
	60	1	2		0.01	0.50	0.03
618.jpg 	25	30	35	57	0.53	0.86	0.65
	30	26	28		0.46	0.93	0.61
	40	16	16		0.28	1.00	0.44
	50	7	7		0.12	1.00	0.22
	60	3	3		0.05	1.00	0.10
621.jpg 	25	51	56	57	0.89	0.91	0.90
	30	28	31		0.49	0.90	0.64
	40	18	20		0.32	0.90	0.47
	50	8	8		0.14	1.00	0.25
	60	5	5		0.09	1.00	0.16

The average Recall and average Precision for the query image class flower for different similarity cut-offs has been tabulated in Table 12. The P – R curves for sample queries of Table 11 and corresponding average Precision & average Recall are shown in Figure 59. Average Precision, average Recall and average F-measure for different similarity cut-offs for the query images of Table 12 have been plotted in Figure 60.

Table 12. Average Recall, Average Precision & Average F - measure. (Whole image color codes). Class – Flower.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.44	0.76	0.55
30	0.33	0.83	0.47
40	0.24	0.84	0.37
50	0.17	0.92	0.29
60	0.07	0.90	0.13

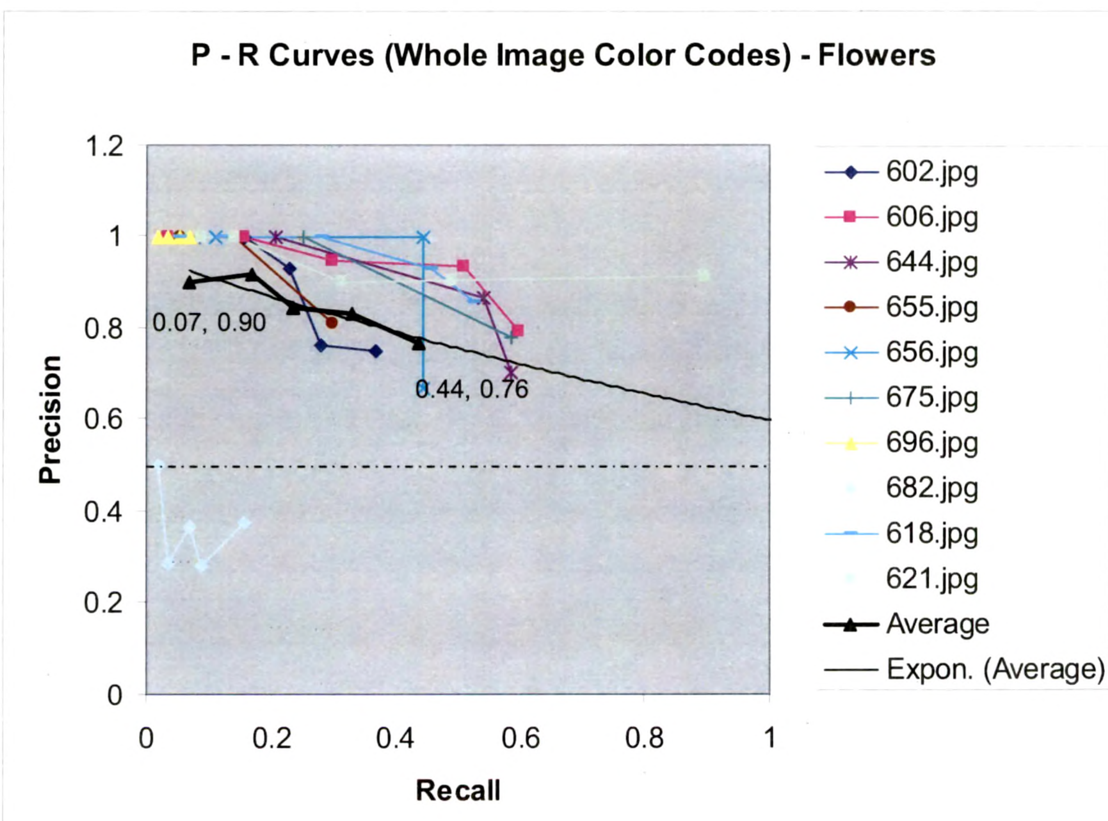


Figure 59. P- R curves (whole image color codes). Class- Flower.

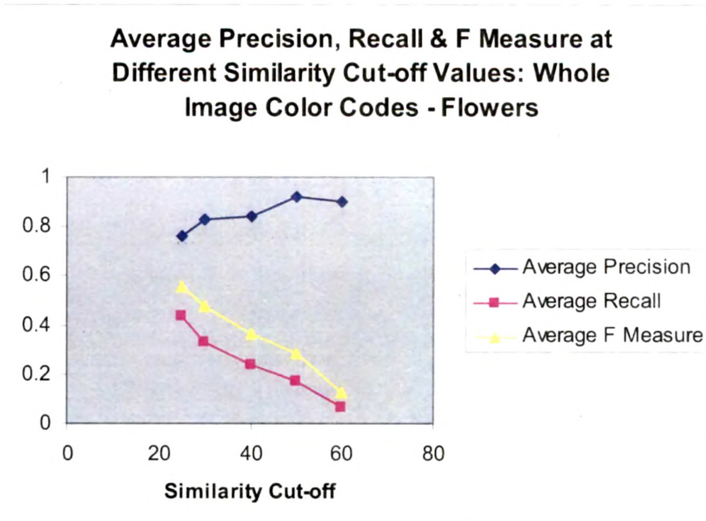


Figure 60. Average Precision, Average Recall, Average F – measures verses Similarity cut-offs. (Whole image color codes). Class – Flower.

Following points are observed:

- The nature of obtained P – R curves is close to ideal P – R curve for some of the query images and similar to practical P – R curves for majority of query images.
- For the variations in colors & poses of foreground objects, background and illumination conditions, high recall with good precision is achieved for many sample queries.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- For many queries, Precision of 1.0 is achieved.
- Poor Precision and Recall values for image 682.jpg are because of blurred (filtered) background constituting major portion of the image.
- At lower cut-offs, images of colored human faces and served restaurant food also gets retrieved because of similar visual cues (Figure 61).
- Range of average performance measures for the class
  - 90 % of average Precision for average 7 % of Recall
  - 76 % of average Precision for 44 % of average Recall
  - Giving only 14 % of fall in average Precision to raise average Recall by 37%.
- The exponentially extended trend line is well above Precision = (0.5) line and not intersecting till average Recall value of 1, implies average precision above 50% for all average Recall values – good performance measures.

6.6.1.6 Query Image Response Example: Class – Flower

The query response of a flower image [Wang, 2001] [SIMPLIcity, on line] having typical foreground colors is shown for similarity cut-off of 40 in Figure 61. The Recall is calculated for total of 57 red / pink colored flower images of the database.

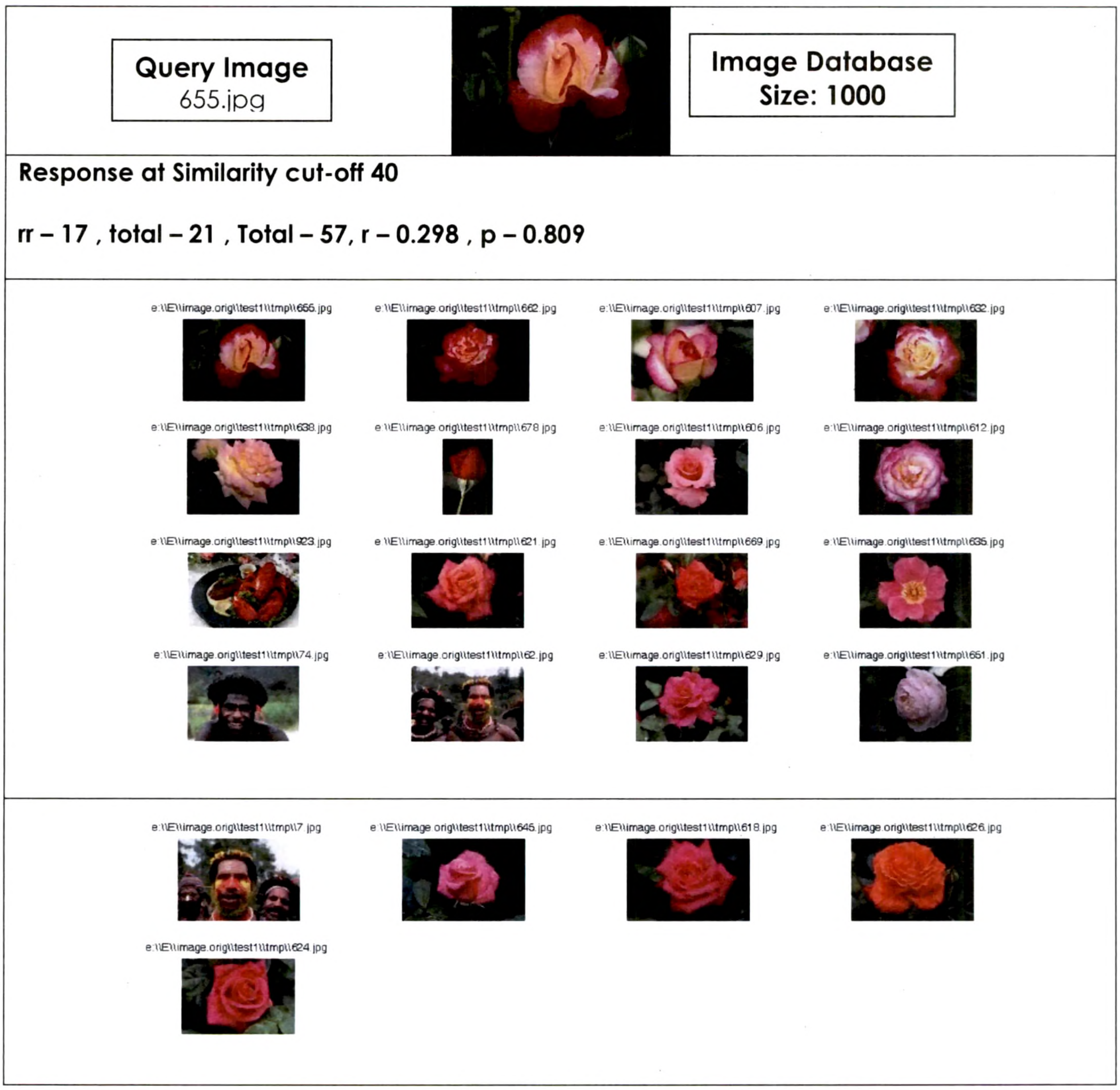


Figure 61. Query response of a flower image at similarity cut-off 40.

6.6.1.7 Query Image Class – Dinosaur

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 1000 images has been shown in Table 13 for
  - 6 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs &
  - 32 queries
- The selected query images possess variations in object-poses, object-colors.
- The backgrounds are simple, multi-color toned & non-textured.
- The foreground objects constitute relatively lesser percentage-portion of the image compared to image class bus.

Table 13. Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class – Dinosaur.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/ p + 1 /r)
406.jpg 	25	42	53	100	0.42	0.79	0.55
	30	35	46		0.35	0.76	0.48
	40	28	34		0.28	0.82	0.42
	50	20	24		0.2	0.83	0.32
	60	12	14		0.12	0.86	0.21
	70	7	7		0.07	1	0.13
408.jpg 	25	52	79	100	0.52	0.66	0.58
	30	48	72		0.48	0.67	0.56
	40	28	40		0.28	0.7	0.40
	50	20	25		0.2	0.8	0.32
	60	8	8		0.08	1	0.15
	70	2	2		0.02	1	0.04
415.jpg 	25	13	21	100	0.13	0.62	0.21
	30	11	13		0.11	0.85	0.19
	40	6	7		0.06	0.86	0.11
	50	4	4		0.04	1	0.08
	60	2	2		0.02	1	0.04

Table 13 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Whole image color codes). Class – Dinosaur.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure = 2 / (1/ p + 1 /r)
429.jpg	25	26	26		0.26	1	0.41
	30	22	22		0.22	1	0.36
	40	14	14	100	0.14	1	0.25
	50	9	9		0.09	1	0.17
	60	5	5		0.05	1	0.10
455.jpg	25	47	75		0.47	0.63	0.54
	30	44	61		0.44	0.72	0.55
	40	30	35	100	0.3	0.86	0.44
	50	14	16		0.14	0.88	0.24
	60	6	7		0.06	0.86	0.11
475.jpg	25	49	59		0.49	0.83	0.62
	30	44	48		0.44	0.92	0.59
	40	28	28	100	0.28	1	0.44
	50	10	10		0.1	1	0.18
	60	3	3		0.03	1	0.06

Table 14 lists the average Recall and average Precision for the query image class dinosaur for different similarity cut-offs. The P – R curves for sample queries of the table and corresponding average Precision & average Recall are shown in Figure 62. Average Precision, average Recall and average F-measures for different similarity cut-offs for the query images of the Table 14 have been plotted in Figure 63.

Table 14. Average Recall, Average Precision & Average F - measure. (Whole image color codes). Class – Dinosaur.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.33	0.75	0.46
30	0.34	0.82	0.48
40	0.22	0.87	0.36
50	0.11	0.92	0.20
60	0.08	0.95	0.15
70	0.05	1	0.09

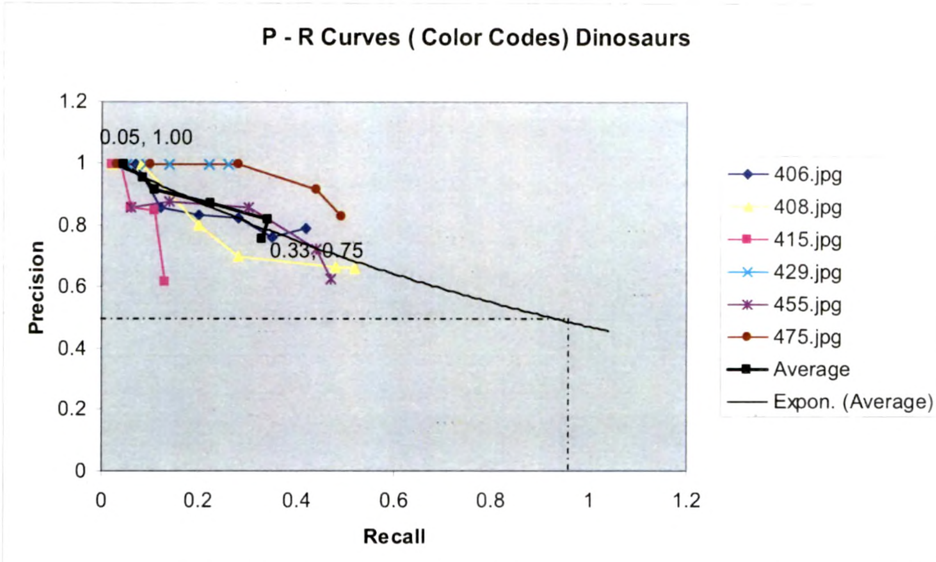


Figure 62. . P- R curves (whole image color codes). Class- Dinosaur.

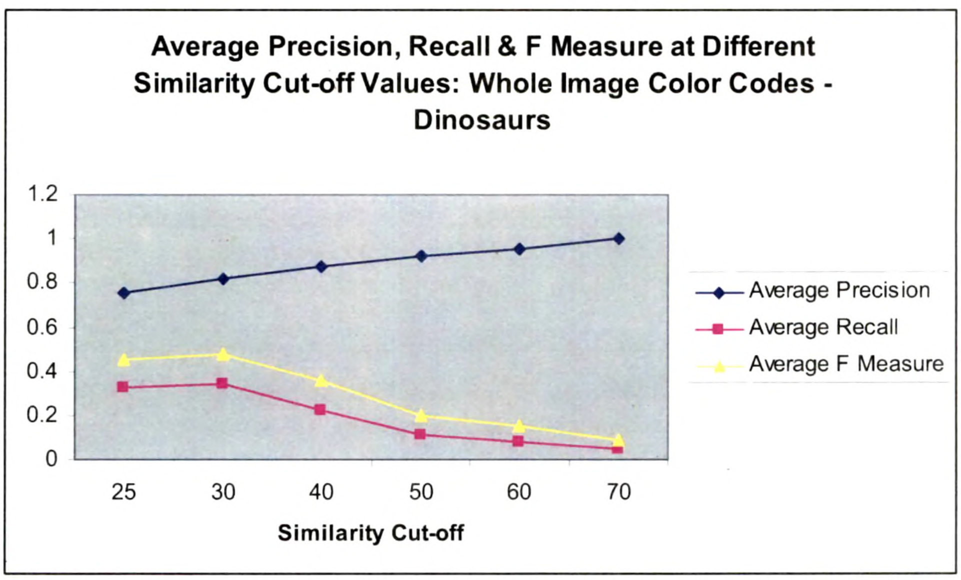


Figure 63. Average Precision, Average Recall, Average F – measures verses Similarity cut-offs. (Whole image color codes). Class – Dinosaur.

Following points are observed:

- The nature of obtained P – R curves is close to ideal P – R curve for some of the query images and similar to practical P – R curves for majority of query images.
- For the variations in colors & poses of foreground objects high recall with good precision is achieved for many sample queries.
- Stricter similarity cut-off increases the Precision at the cost of Recall.

- For many queries, Precision of 1.0 is achieved.
- Range of average performance measures for the class
  - 100 % of average Precision for 5 % of average Recall
  - 75 % of average Precision for 33 % of average Recall
  - Giving 25 % of fall in Precision to raise Recall by 28 %.
- The exponentially extended trend line intersects average Precision = (0.5) line at average Recall at value 0.95 (approx.) implies good performance measures.

6.6.1.8 Query Image Response Example: Class - Dinosaur

The query response of a dinosaur image [Wang, 2001] [SIMPLIcity, on line] is shown for similarity cut-off of 40 in Figure 64.

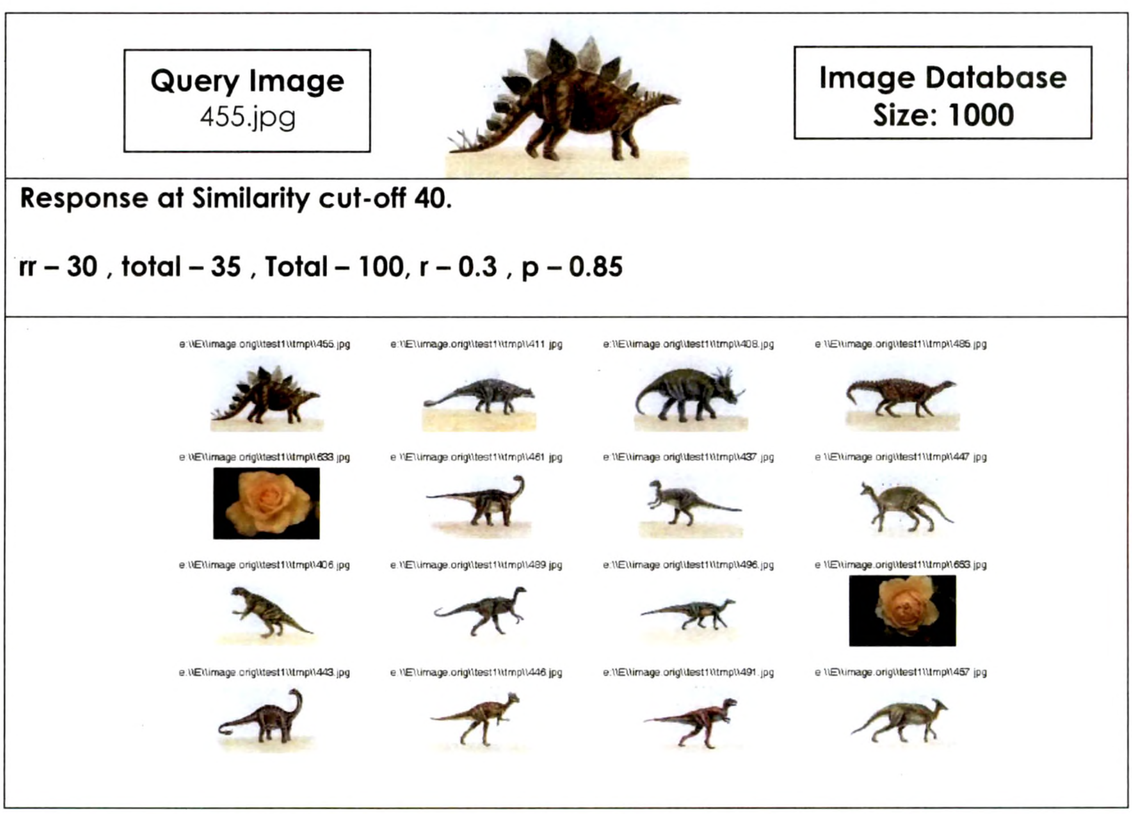


Figure 64. Query response of a dinosaur image at similarity cut-off 40.

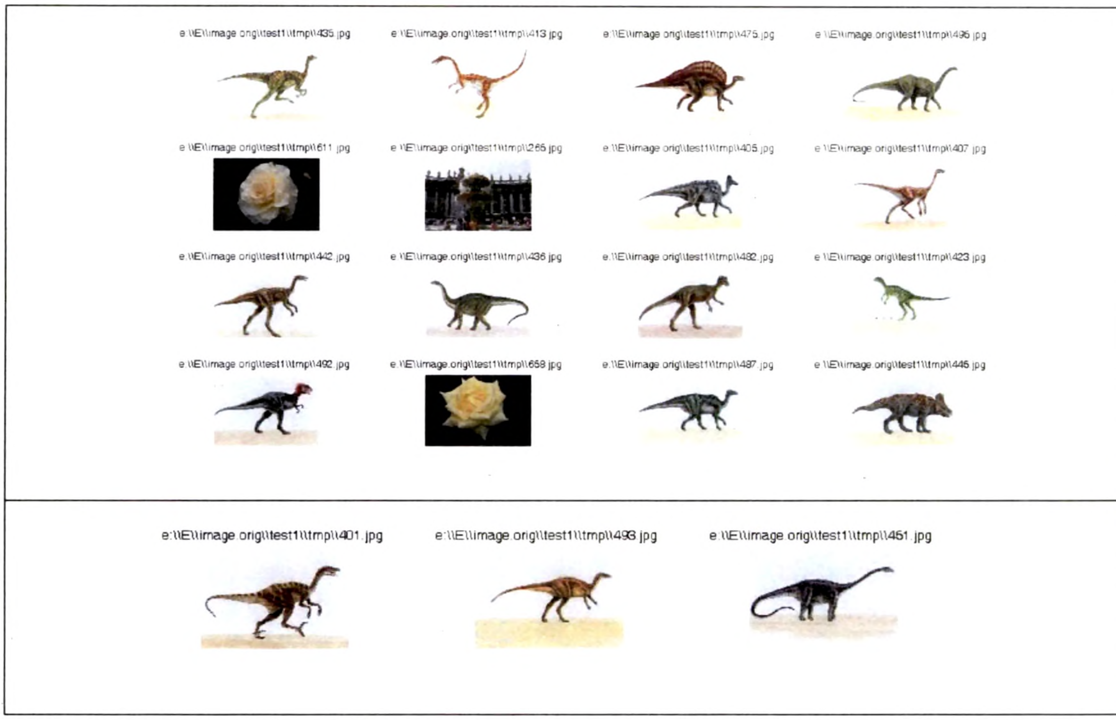


Figure 64 (Contd.). Query response of a dinosaur image at similarity cut-off 40.

6.6.1.9 Query Image Response Examples: Other Classes

The query responses shown in Figure 65 & Figure 66 can well illustrate the issue of subjectivity involved in the intention of user and image content description. Is user intending to retrieve blue skied images or images of blue sky with white clouds? Or, is he aiming to get seashore images or images containing water? The answer will determine the number of relevant images retrieved and hence the Precision, Recall & finally the performance of the system. The Figure 67 to Figure 70 show the query responses of images of other classes of SIMPLICity [Wang, 2001] [SIMPLIcity, on line].

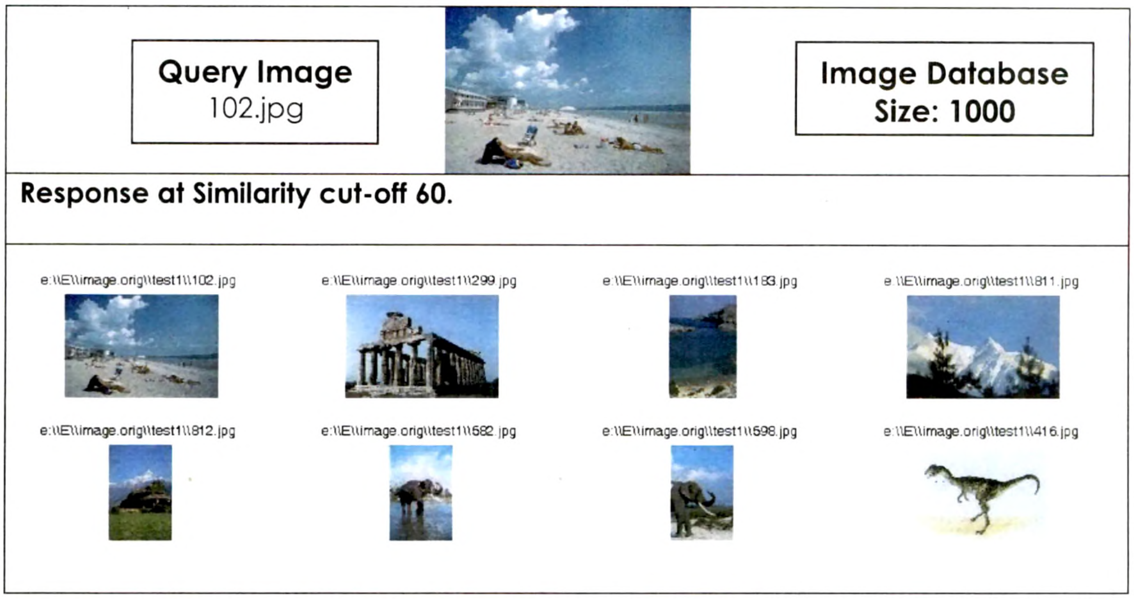


Figure 65. Query response of a sea-shore image at similarity cut-off 60.

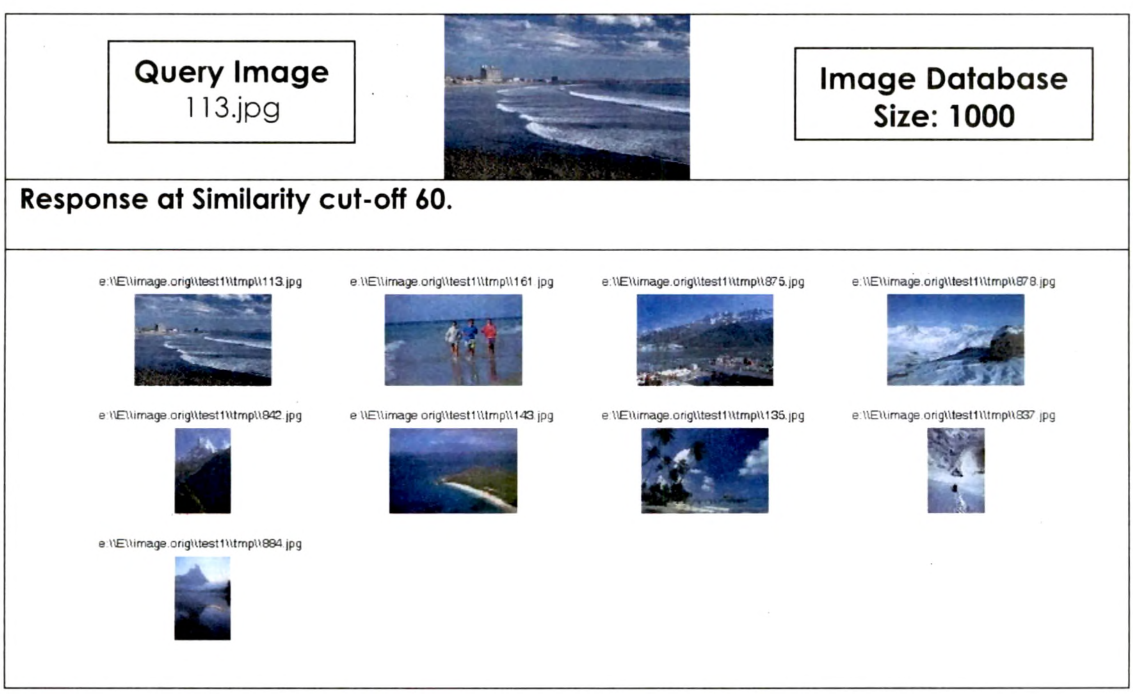


Figure 66. Query response of another sea-shore image at similarity cut-off 60.

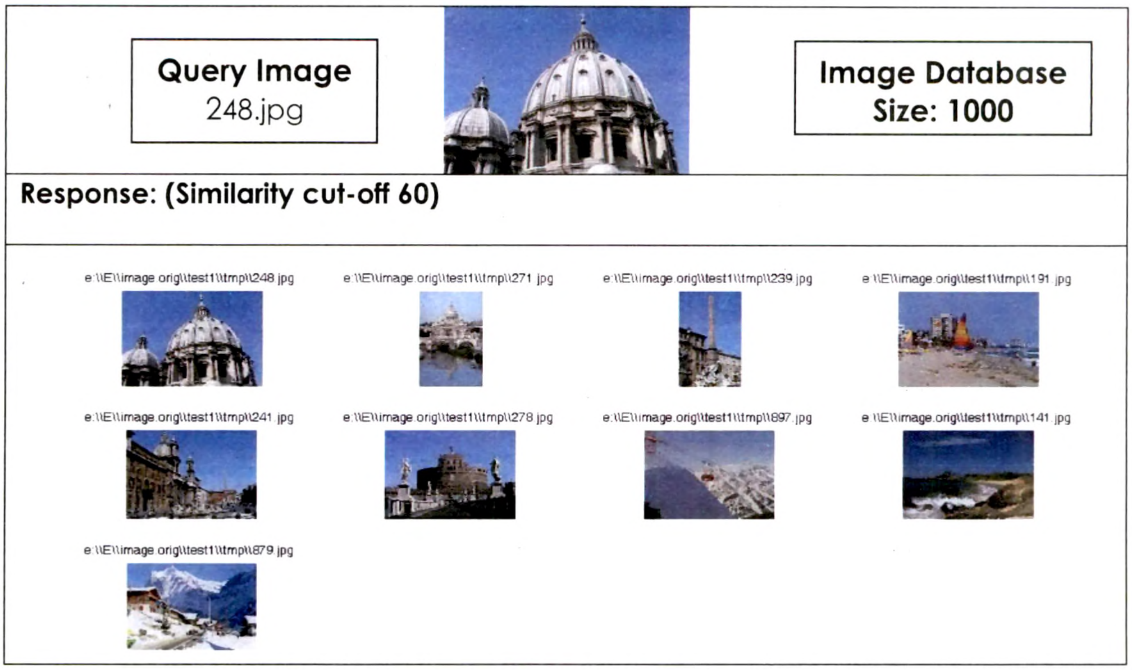


Figure 67. Query response of a sculpture image at similarity cut-off 60.

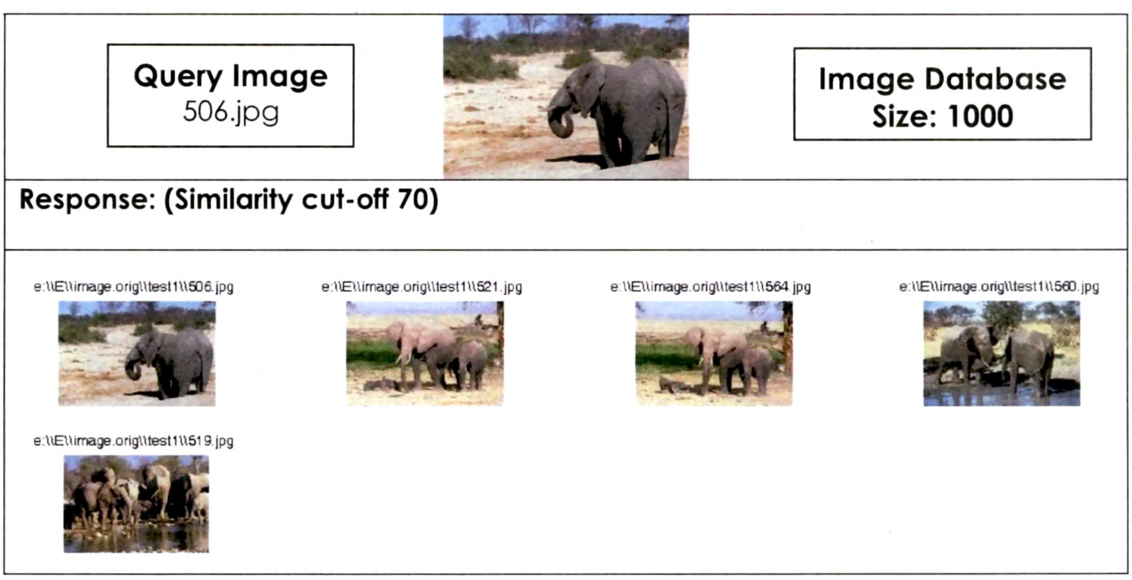


Figure 68. Query response of an elephant image at similarity cut-off 70.

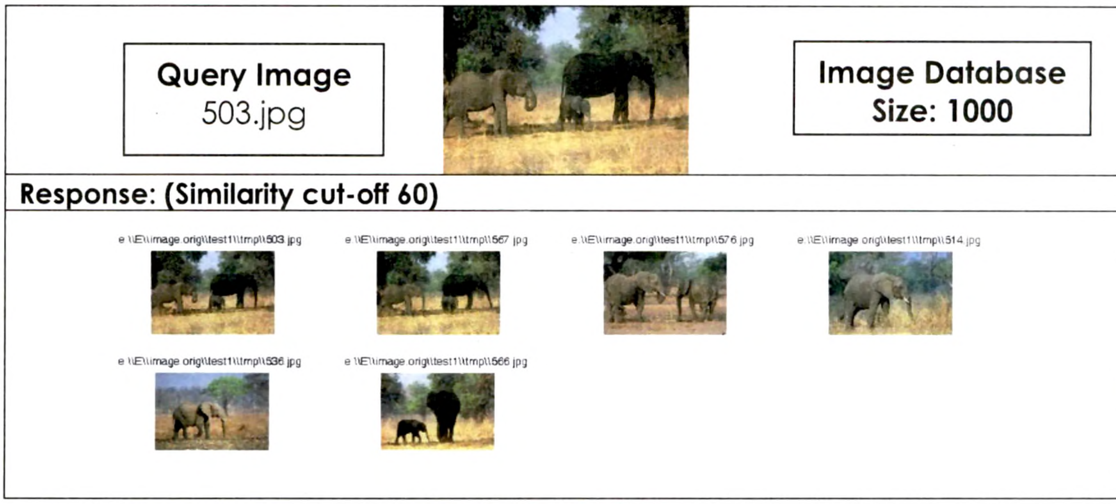


Figure 69. Query response of another elephant image at similarity cut-off 60.

Figure 70. Query response of served food image at similarity cut-off 60.

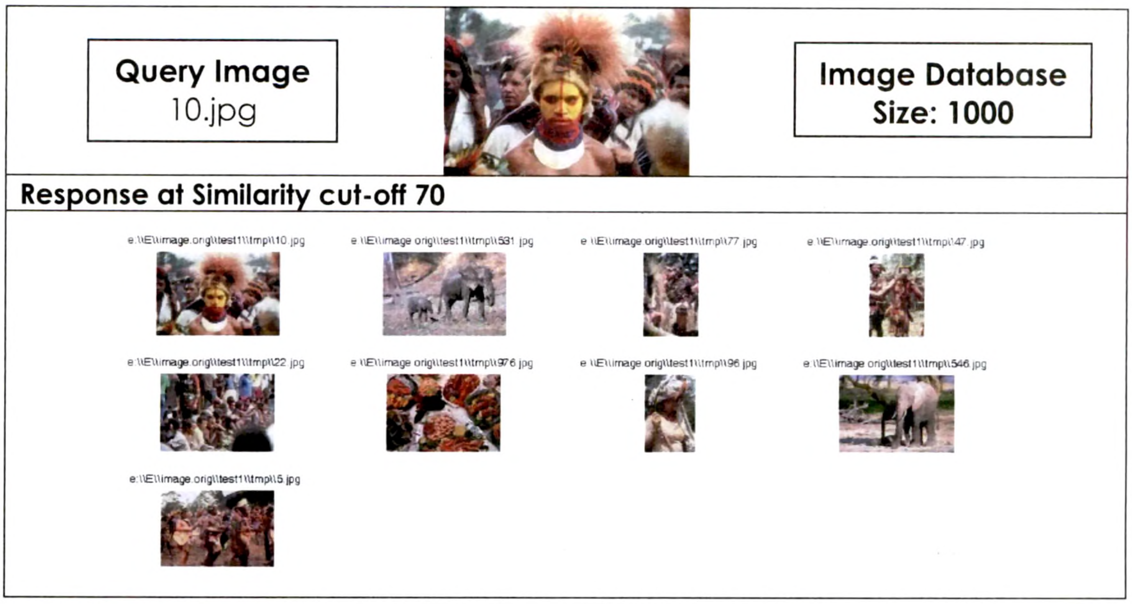


Figure 71. Query response of an image of a tribal man with color painted on face at similarity cut-off 60.

The average Recall, average Precision and average F-measures for all test queries have been tabulated in Table 15 and class wise P – R curves and method average P – R curves are shown in Figure 72. The average Recall, average Precision and average F-measures for all test queries for the method have been plotted in Figure 73.

Table 15. Average Recall, Average Precision & Average F - measure. (Whole image color codes). All queries for the method.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.44	0.69	0.54
30	0.39	0.74	0.51
40	0.27	0.78	0.40
50	0.17	0.83	0.29
60	0.11	0.86	0.20
70	0.06	0.96	0.12

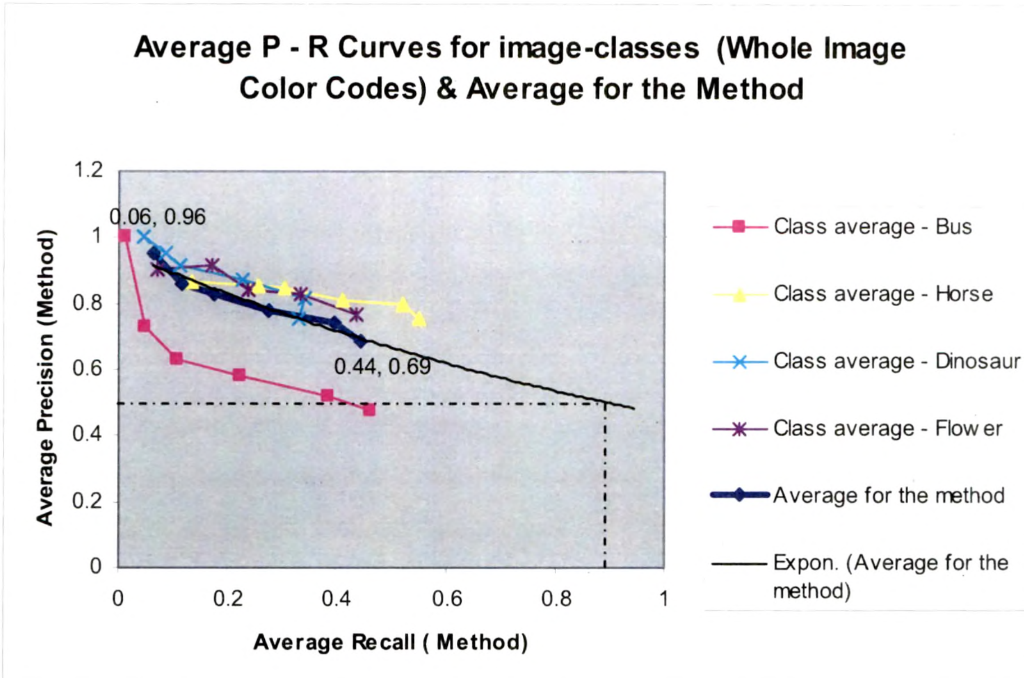


Figure 72. P- R curves (whole image color codes). All queries for the method.

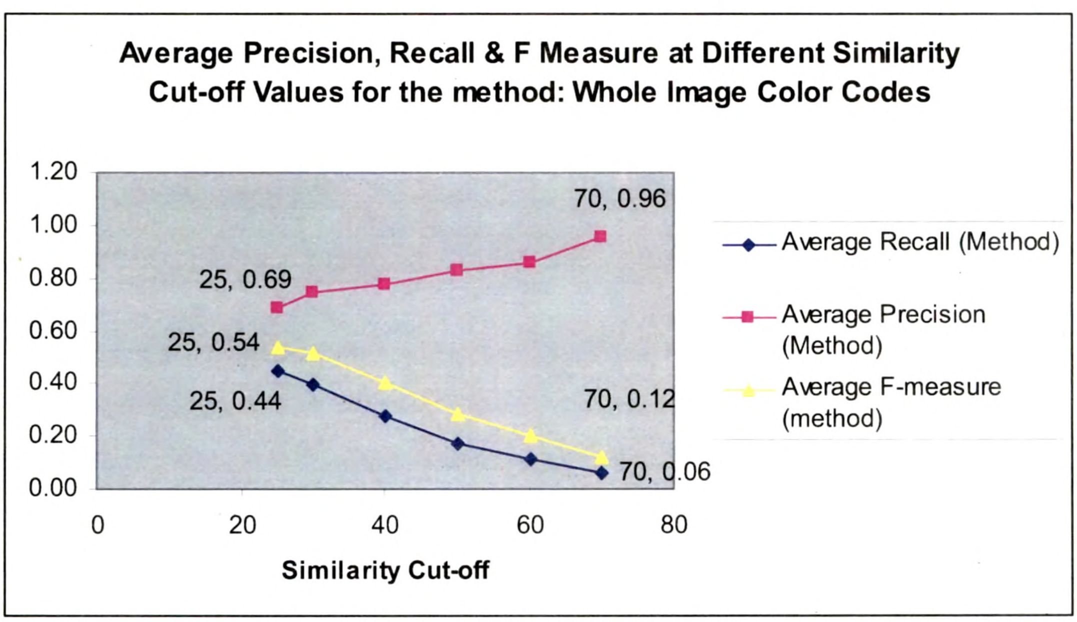


Figure 73. Average Precision, Average Recall, Average F – measures verses Similarity cut-offs. (Whole image color codes). All queries for the method.

6.6.2 Discussion

- The performance has been evaluated on 1000 images of standard data base [Wang, 2001] [SIMPLIcity, on line] consisting of 10 classes of images for total 161 queries with different similarity cut-offs for 33 query images of 4 different classes.
- The method is robust to illumination, pose and view point variations as it is based on broader color descriptors.
- The feature extraction and retrieval methods require lesser computations compared to boundary detection based proposed methods.
- The broader descriptors are characterized to yield higher Recall. So are the color codes.
- The method works well even on images of poor quality and low resolutions.
- The ranking of nearly similar images is high.
- The method is not sensitive to image scale and rotation.
- The Precision measures obtained for majority of the queries of all four classes are significantly high with good Recall.
- Range of average performance measures for all queries of all classes
  - 96 % of average Precision for 6 % of average Recall
  - 69 % of average Precision for 44 % of average Recall
  - Giving 27 % of fall in average Precision to raise average Recall by 38%.
- The exponentially extended trend line intersects average Precision = (0.5) line at average Recall at value 0.90 (approx.) implies good performance measures.
- The results with proposed method are better than many reported in literature.

6.7 Foreground Color Codes Based CBIR

Foreground based image retrieval enables user to search images on the basic of objects contained in the image. The exclusion of background narrows down subjectivity induced diversity about the image content. Precisely detected foreground encompassing prominent boundaries yielding foreground region attributes and color codes of the foreground are used as combined features for image retrieval. The normalized histogram constructed for foreground region is compared with that of image of image database. The algorithm is applied on color codes of foreground for measuring color distribution similarity of foreground regions of images under considerations. Following method specific steps replace corresponding generic Steps 3 & 4 of Algorithm 4, Section 6.5 :

Step 3: Read (or extract) foreground color code features of given query image.

Step 4: For every image-feature-file of target folder,

Read corresponding foreground color code features of the image-feature-file of target folder.

Calculate (dis)similarity_index $_i$ = $\sum abs(h_{qj} - h_{ij})$, for 1 < j <= number of Bins, Where,

h_{qj} indicates j th bin of normalized histogram of color codes for the query image

h_{ij} indicates j th bin of normalized histogram of color codes for i th image of database

Store path of data base image, needed for display.

Algorithm 6. Foreground color codes based image retrieval.

6.7.1 Performance Evaluation

The performance of the method has been tested on image database of SIMPLIcity [Wang, 2001] [SIMPLIcity, on line] consisting of 371 images. Exhaustive performance evaluation has been carried out for two classes of database – Bus and flower. Recall, Precision and F –measure are computed for sample queries of each class of images for different similarity cut-offs. Average Recall, Average Precision and Average F – measures for the class are tabulated to analyze performance of the method for given class of images. P – R curves for query responses along with Average Precision and Average Recall are plotted for performance analysis. Average Recall, Average Precision and Average F – measures are also plotted for different similarity cut-off.

6.7.1.1 Query Image Class: Bus

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 371 images has been shown in Table 16 for
  - 11 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs &
  - 57 queries

- The set of selected query images is same as the set used for image retrieval using whole image color codes.

Table 16. Precision, Recall & F –measure at different similarity cut-offs. (Foreground color codes). Class - Bus.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
300.jpg 	25	64	74	100	0.64	0.86	0.73
	30	56	60		0.56	0.93	0.70
	40	36	38		0.36	0.95	0.52
	50	24	24		0.24	1.00	0.39
	60	10	10		0.1	1.00	0.18
	70	4	4		0.04	1.00	0.08
310.jpg 	25	59	61	100	0.59	0.97	0.73
	30	52	53		0.52	0.98	0.68
	40	39	39		0.39	1.00	0.56
	50	25	25		0.25	1.00	0.40
	60	13	13		0.13	1.00	0.23
	70	2	2		0.02	1.00	0.04
358.jpg 				100			
	25	21	22		0.21	0.95	0.34
	30	19	20		0.19	0.95	0.32
	40	7	8		0.07	0.88	0.13
	50	3	3		0.03	1.00	0.06
	60	2	2		0.02	1.00	0.04
315.jpg 	25	41	47	100	0.41	0.87	0.56
	30	32	37		0.32	0.86	0.47
	40	25	25		0.25	1.00	0.40
	50	12	12		0.12	1.00	0.21
	60	6	6		0.06	1.00	0.11
319.jpg 	25	8	47	100	0.08	0.17	0.11
	30	6	38		0.06	0.16	0.09
	40	3	22		0.03	0.14	0.05
	50	3	18		0.03	0.17	0.05
	60	1	5		0.01	0.20	0.02

Table 16 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Foreground color codes). Class - Bus.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
326.jpg	25	26	59		0.26	0.44	0.33
	30	18	64		0.18	0.28	0.22
	40	8	24		0.08	0.33	0.13
	50	3	5	100	0.03	0.60	0.06
	60	2	2		0.02	1.00	0.04
365.jpg	25	62	73		0.62	0.85	0.72
	30	56	61		0.56	0.92	0.70
	40	33	34	100	0.33	0.97	0.49
	50	11	11		0.11	1.00	0.20
	60	2	2		0.02	1.00	0.04
388.jpg	25	74	78		0.74	0.95	0.83
	30	65	67		0.65	0.97	0.78
	40	39	40	100	0.39	0.98	0.56
	50	21	22		0.21	0.95	0.34
	60	7	7		0.07	1.00	0.13
366.jpg	25	15	57		0.15	0.26	0.19
	30	10	39		0.1	0.26	0.14
	40	8	28	100	0.08	0.29	0.13
	50	5	12		0.05	0.42	0.09
	60	2	2		0.02	1.00	0.04
344.jpg	25	30	32		0.3	0.94	0.45
	30	21	23		0.21	0.91	0.34
	40	10	11	100	0.1	0.91	0.18
	50	3	3		0.03	1.00	0.06
	60	2	2		0.02	1.00	0.04
369.jpg	25	77	82		0.77	0.94	0.85
	30	69	71		0.69	0.97	0.81
	40	44	44	100	0.44	1.00	0.61
	50	16	16		0.16	1.00	0.28
	60	4	4		0.04	1.00	0.08

Table 17. Average Recall, Average Precision & Average F -measure. (Foreground color codes). Class – Bus.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.40	0.75	0.52
30	0.34	0.75	0.46
40	0.21	0.77	0.33
50	0.11	0.83	0.19
60	0.04	0.93	0.08
70	0.03	1.00	0.06

The average Precision and average Recall for class Bus have been tabulated in Table 17 and plotted in Figure 74 along with P – R curves for individual bus image query responses. The average Recall, average Precision and average F-measures with respect to similarity cut-off for all test queries of the class have been presented in Figure 75.

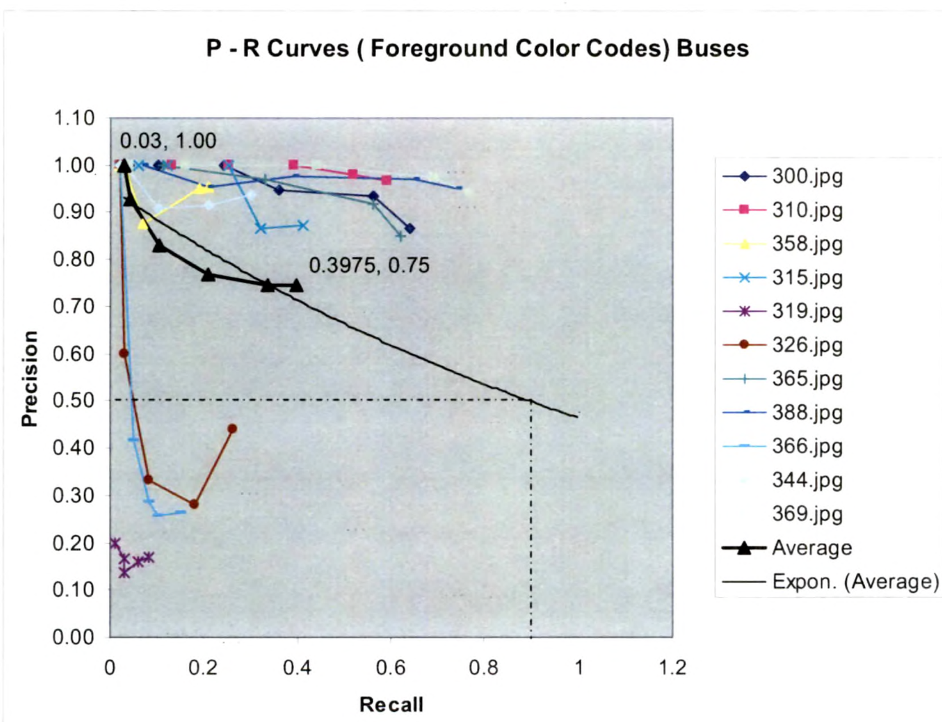


Figure 74. P- R curves (Foreground color codes). Class - Bus.

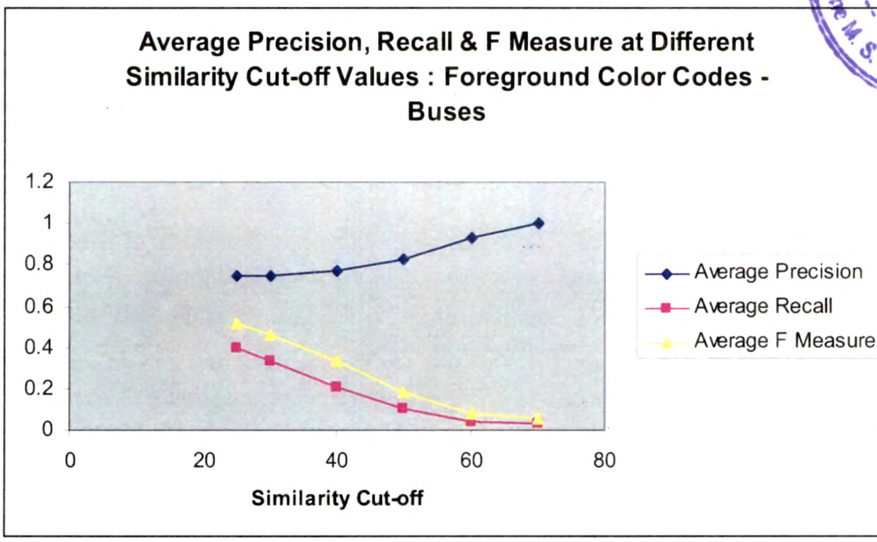


Figure 75. P- R curves (Foreground color codes). Class - Bus.

Following points are observed:

- The nature of obtained P – R curves matches with the practical P – R curves.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- Despite vast variations in bus colors, poses and illumination conditions, high recall with good precision is achievable for many sample queries.
- For all but one queries, Precision of 1.0 is achieved.
- The Precision and recall measures have been improved for all but one (319.jpg) query images.
- Improvement in precision is contributed by two factors – only foreground region based comparison and reduced image database size.
- Range of average performance measures for the class
  - 100 % of average Precision for 3 % of average Recall
  - 75 % of average Precision for 40 % of average Recall
  - Giving 25 % of fall in average Precision to raise average Recall by 37 %
- The exponentially extended trend line intersects average Precision = (0.5) line at average Recall at value 0.9 (approx.) implies quite good performance measures for images of the class.

6.7.1.2 Query Response Example: Class - Bus

The query response of a bus image [Wang, 2001] [SIMPLIcity, on line] at similarity cut-off of 25 is shown in Figure 76. The Recall of 59 % with 97 % of Precision is to be noted.

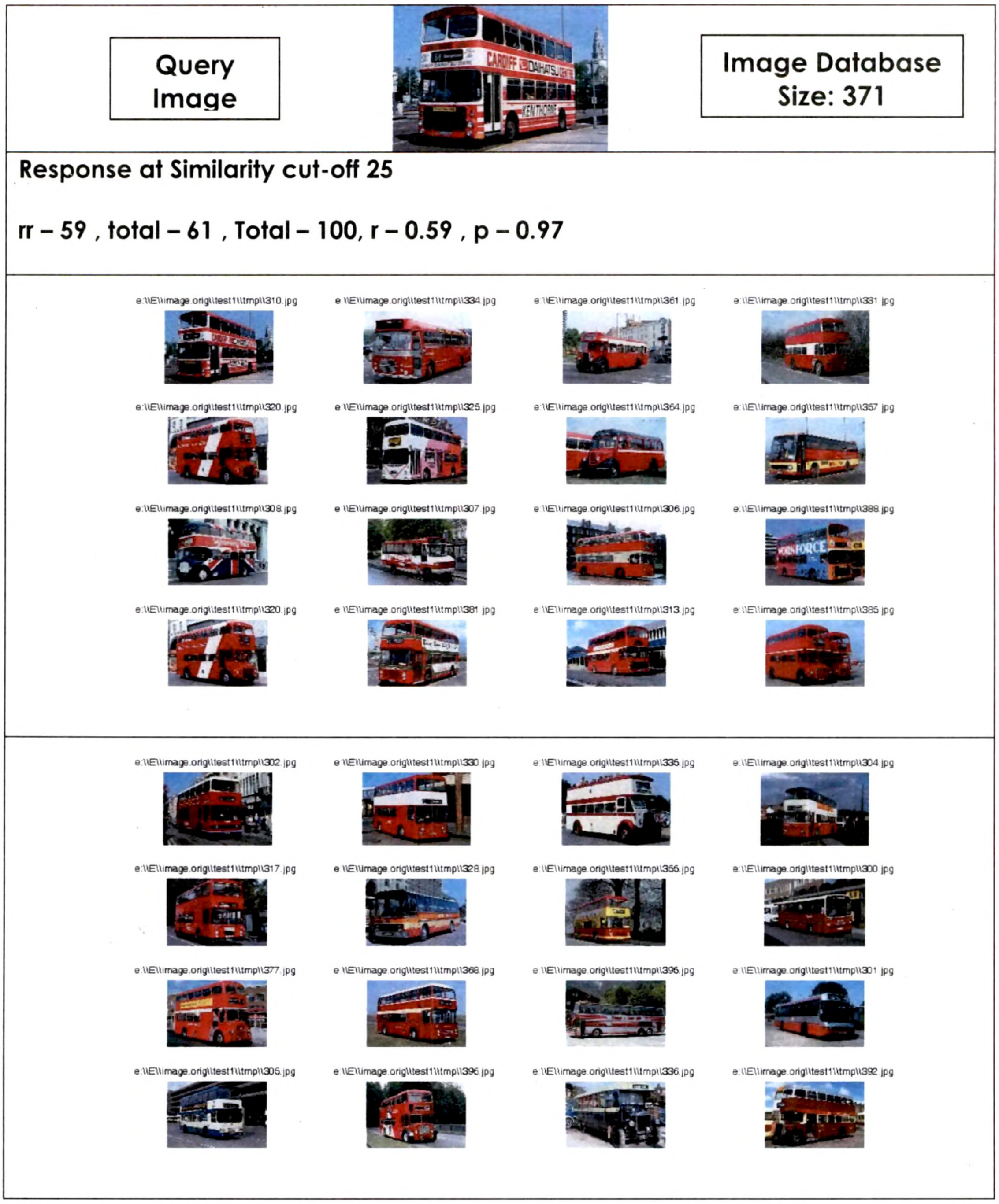


Figure 76. Query response of a bus image at similarity cut-off 25. (FGCC)

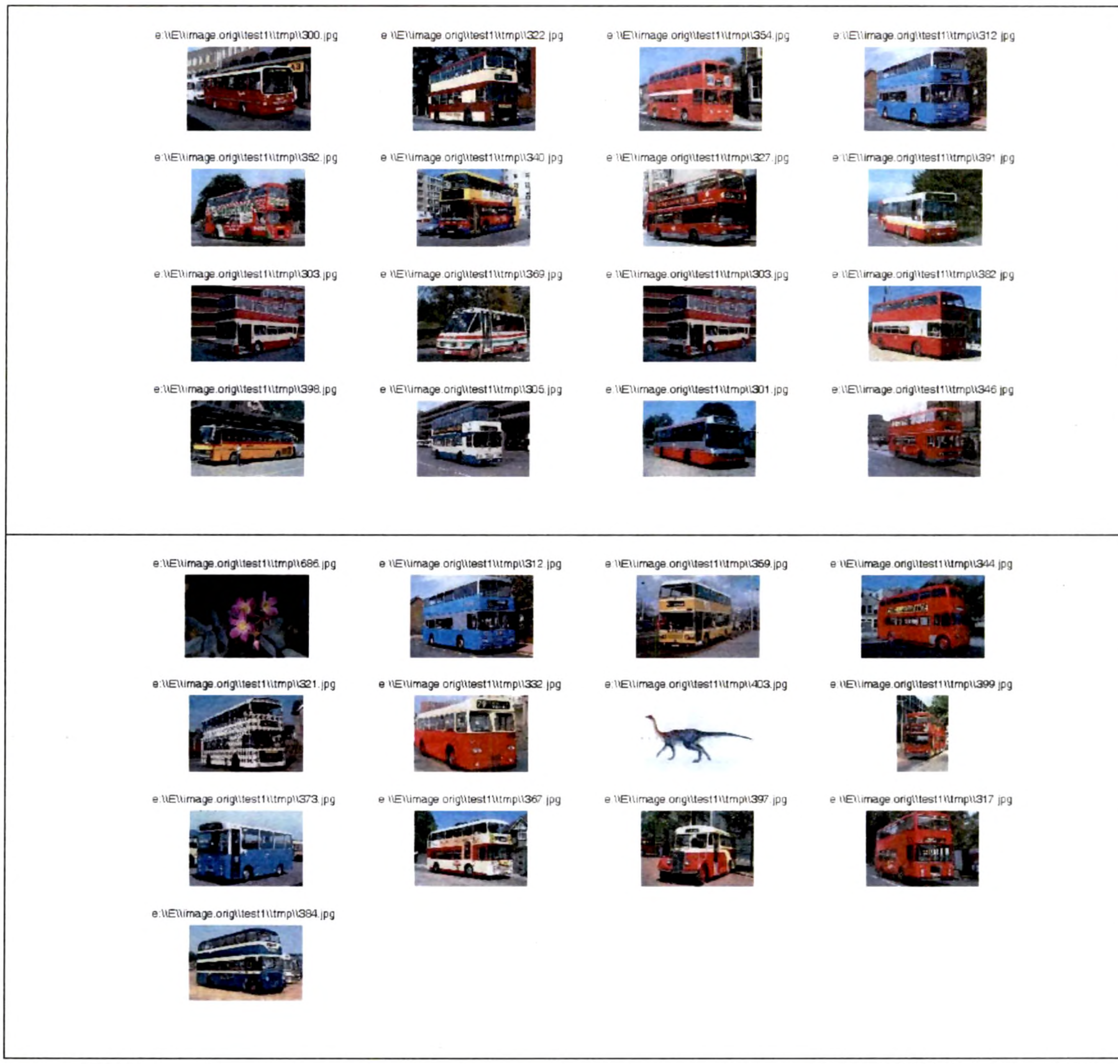


Figure 76 (Contd.). Query response of a bus image at similarity cut-off 25. (FGCC)

6.7.1.3 Query Image Class – Flower

- The performance evaluation on image database [Wang, 2001] [SIMPLIcity, on line] consisting of 371 images has been shown in Table 18 for
  - 10 varieties of query images [Wang, 2001] [SIMPLIcity, on line] for different similarity cut-offs &
  - 51 queries
- The set of selected query images consists of 8 images used in the set for image retrieval using whole image color codes. Two images used in the first set have been replaced because of their inferior foreground extraction.

Table 18. Precision, Recall & F –measure at different similarity cut-offs. (Foreground color codes). Class - Flower.

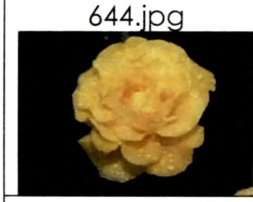
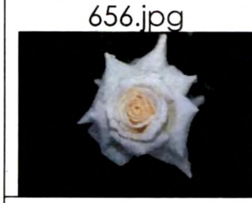
Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
606.jpg 	25	33	34	57	0.58	0.97	0.73
	30	31	31		0.54	1.00	0.70
	40	27	27		0.47	1.00	0.64
	50	20	20		0.35	1.00	0.52
	60	11	11		0.19	1.00	0.32
	70	9	9		0.16	1.00	0.27
644.jpg 	25	15	45	24	0.63	0.33	0.43
	30	15	37		0.63	0.41	0.50
	40	13	30		0.54	0.43	0.48
	50	11	26		0.46	0.42	0.44
	60	10	18		0.42	0.56	0.48
655.jpg 	25	17	50	57	0.30	0.34	0.32
	30	15	35		0.26	0.43	0.33
	40	10	17		0.18	0.59	0.27
	50	5	8		0.09	0.63	0.15
	60	4	4		0.07	1.00	0.13
656.jpg 	25	1	19	9	0.11	0.05	0.07
	30	1	11		0.11	0.09	0.10
	40	1	5		0.11	0.20	0.14
	50	1	2		0.11	0.50	0.18
	60	1	1		0.11	1.00	0.20
696.jpg 	25	12	13	57	0.21	0.92	0.34
	30	5	5		0.09	1.00	0.16
	40	4	4		0.07	1.00	0.13
	50	2	2		0.03	1.00	0.07
	60	2	2		0.03	1.00	0.07
675.jpg 	25	17	64	24	0.71	0.27	0.39
	30	17	56		0.71	0.30	0.42
	40	16	42		0.67	0.38	0.48
	50	16	34		0.67	0.47	0.55
	60	13	28		0.54	0.46	0.50

Table 18 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Foreground color codes). Class - Flower.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
682.jpg	25	32	34		0.56	0.94	0.70
	30	30	31		0.53	0.97	0.68
	40	27	28	57	0.47	0.96	0.63
	50	20	20		0.35	1.00	0.52
	60	13	13		0.23	1.00	0.37
618.jpg	25	26	27		0.46	0.96	0.62
	30	25	26		0.44	0.96	0.60
	40	20	21	57	0.35	0.95	0.51
	50	18	18		0.32	1.00	0.48
	60	15	15		0.26	1.00	0.42
621.jpg	25	27	28		0.47	0.96	0.63
	30	24	25		0.42	0.96	0.59
	40	20	21	57	0.35	0.95	0.51
	50	18	18		0.32	1.00	0.48
	60	15	15		0.26	1.00	0.42
640.jpg	25	5	5		0.5	1.00	0.67
	30	4	4		0.4	1.00	0.57
	40	3	3	10	0.3	1.00	0.46
	50	2	2		0.2	1.00	0.33
	60	1	1		0.1	1.00	0.18

Table 19. Average Recall, Average Precision & Average F - measure. (Foreground color codes). Class – Flower.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
25	0.45	0.68	0.54
30	0.41	0.71	0.52
40	0.35	0.75	0.48
50	0.29	0.80	0.43
60	0.22	0.90	0.35
70	0.16	1.00	0.28

The average Precision and average Recall for class Flower have been tabulated in Table 19 and plotted in Figure 77 along with P – R curves for individual query responses. The average Recall, average Precision and average F-measures for all test queries of the class have been presented in Figure 78.

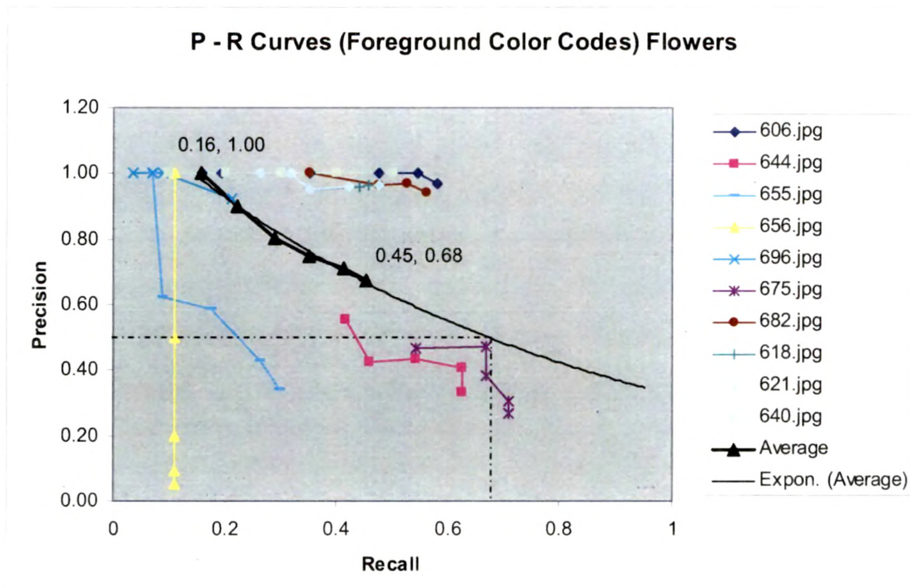


Figure 77. P- R curves (Foreground color codes). Class- Flower.

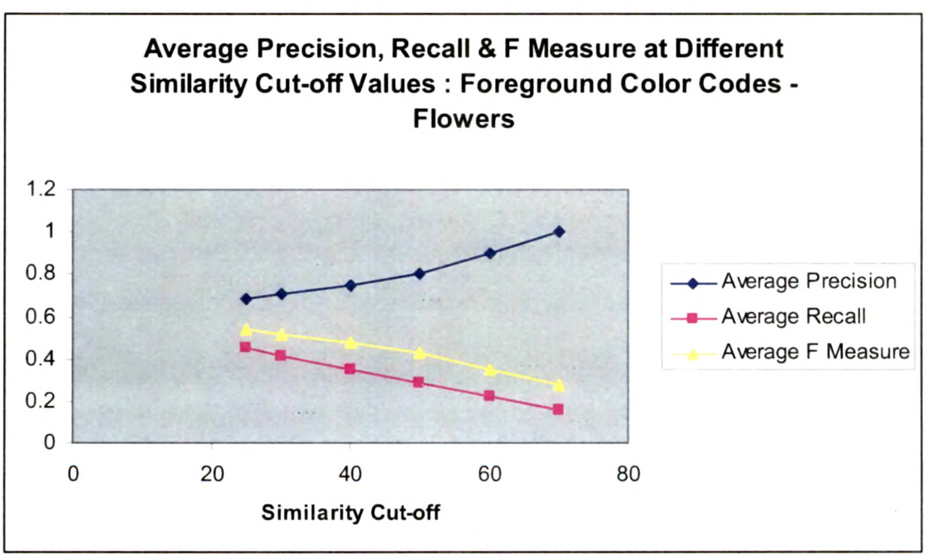


Figure 78. Avg. Precision, Avg. Recall, Avg. F – measures verses Similarity cut-offs. (Foreground color codes). Class – Flower.

Following points are observed:

- The nature of obtained P – R curves matches with the practical P – R curves.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- Despite vast variations in foreground colors and illumination conditions, high recall with good precision is achievable for many sample queries.
- For many queries, Precision of 1.0 is achieved for reasonable Recall.
- Range of average performance measures for the class
    - 100 % of average Precision for 16 % of average Recall
    - 68 % of average Precision for 45% of average Recall
    - Giving 32 % of fall in average Precision to raise average Recall by 29 %
- The exponentially extended trend line intersects average Precision = (0.5) line at average Recall at value 0.67 (approx.) implies good performance measures for images of the class.

6.7.1.4 Query Response Example: Class - Flower

The query responses of two different flower images [Wang, 2001] [SIMPLIcity, on line] at lowest similarity cut-off of 25 are shown in Figure 79 & Figure 80 respectively. The selected query images are of typical foreground colors.

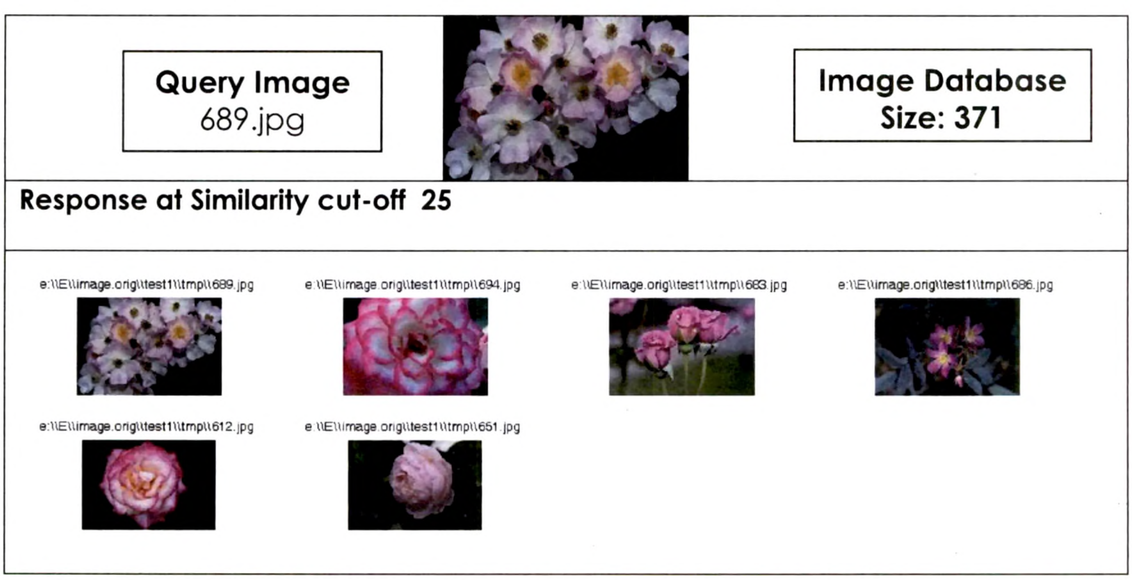


Figure 79. Query response of a flower image at similarity cut-off 25. (FGCC)

Figure 80. Query response of another flower image at similarity cut-off 25. (FGCC)

6.7.2 Discussion

- The performance has been evaluated on 371 images of standard data base [Wang, 2001] [SIMPLIcity, on line] consisting of all images of two classes and some images from other classes for total 115 queries with different similarity cut-offs for 21 query images of 2 different classes.
- The method is not suitable for images containing very small foreground objects and objects touching to image boundaries which may not be encompassed by prominent boundaries.
- The extracted background excludes background and related features from comparison enabling user to perform search based on objects contained in the image.
- The method is robust to illumination and less sensitive to pose and view point variations as it is based on broader color descriptors of the extracted foreground.
- The feature extraction and retrieval methods require significant computations.
- The performance of the method is not sensitive to regions attached to foreground objects, because, for given image, such regions can be made to constitute small percentage of total extracted foreground by performing feature extraction at higher wavelet level. The low resolution and poor

quality of images affect foreground extraction and hence performance of the method.

- The Precision measures obtained for majority of the queries are significantly high with good Recall.
- The exponentially extended trend line intersects average Precision = (0.5) line of both classes at average Recall at values 0.9 & 0.67 (approx.) respectively, imply good performance measures.

6.8 Foreground Shape Correlation Based CBIR

The normalized unsegmented foreground region has been utilized as the feature for the image comparison. The method specific steps, replacing Step 3 & Step 4 of algorithm specified in Algorithm 4, Section 6.5 are:

Step 3: Read (or extract) normalized unsegmented foreground region features for the query image. Call it Rq.

Step 4: For every image-feature-file of target folder,

Read normalized unsegmented foreground region features of the image-feature-file of target folder. Let us call it Rd_i.

Calculate correlation coefficients of Rq & Rd_i.

Find the significant correlation coefficient.

Calculate (dis)similarity_index$_i$ = 100 – abs(significant correlation coefficient of Rq & Rd_i) * 100

Algorithm 7. Foreground shape correlation based image retrieval.

Unsegmented foreground regions have been obtained by excluding background regions found in step 8 of Algorithm 3.

The query response for the method is shown in Figure 82. Note that the performance & results with 0 % weight of foreground color code attributes in the composite similarity constraint of next method – Foreground Color Codes & Shape Correlation corresponds to this method of image retrieval.

6.8.2 Performance Evaluation

The performance of the method has been tested on image database of SIMPLIcity [Wang, 2001] [SIMPLIcity, on line] consisting of 371 images. The Precision, Recall and F – measures are shown in Table 19 for 10 images of class Flower and total of 20 queries. Corresponding P – R curves are plotted in Figure 81.

Table 20. Precision, Recall & F –measure at different similarity cut-offs. (Foreground shape correlation). Class - Flower.

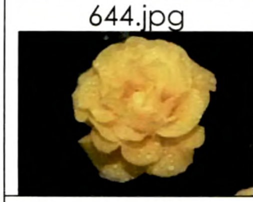
Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
606.jpg 	60	39	41	100	0.39	0.95	0.55
	70	4	4	100	0.04	1.00	0.08
644.jpg 	60	45	47	100	0.45	0.96	0.61
	70	23	23	100	0.23	1.00	0.37
655.jpg 	60	10	10	100	0.1	1.00	0.18
	70	1	1	100	0.01	1.00	0.02
656.jpg 	60	34	36	100	0.34	0.94	0.50
	70	7	7	100	0.07	1.00	0.13
696.jpg 	60	1	1	100	0.01	1.00	0.02
	70	1	1	100	0.01	1.00	0.02
675.jpg 	60	2	2	100	0.02	1.00	0.04
	70	1	1	100	0.01	1.00	0.02

Table 20 (Contd.). Precision, Recall & F –measure at different similarity cut-offs. (Foreground shape correlation). Class - Flower.

Query Image	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F measure= 2/(1/ p + 1/r)
682.jpg 	60	4	5	100	0.04	0.80	0.08
	70	3	3	100	0.03	1.00	0.06
618.jpg 	60	42	45	100	0.42	0.93	0.58
	70	19	19	100	0.19	1.00	0.32
621.jpg 	60	47	50	100	0.47	0.94	0.63
	70	26	26	100	0.26	1.00	0.41
640.jpg 	60	6	7	100	0.06	0.86	0.11
	70	2	2	100	0.02	1.00	0.04

Table 21. Average Recall, Average Precision & Average F - measure. (Foreground Shape correlation). Class – Flower.

Similarity cut-off	Average Recall	Average Precision	Average F measure = 2 / (1/Avg.p + 1/Avg.r)
60	0.23	0.94	0.37
70	0.09	1.00	0.16

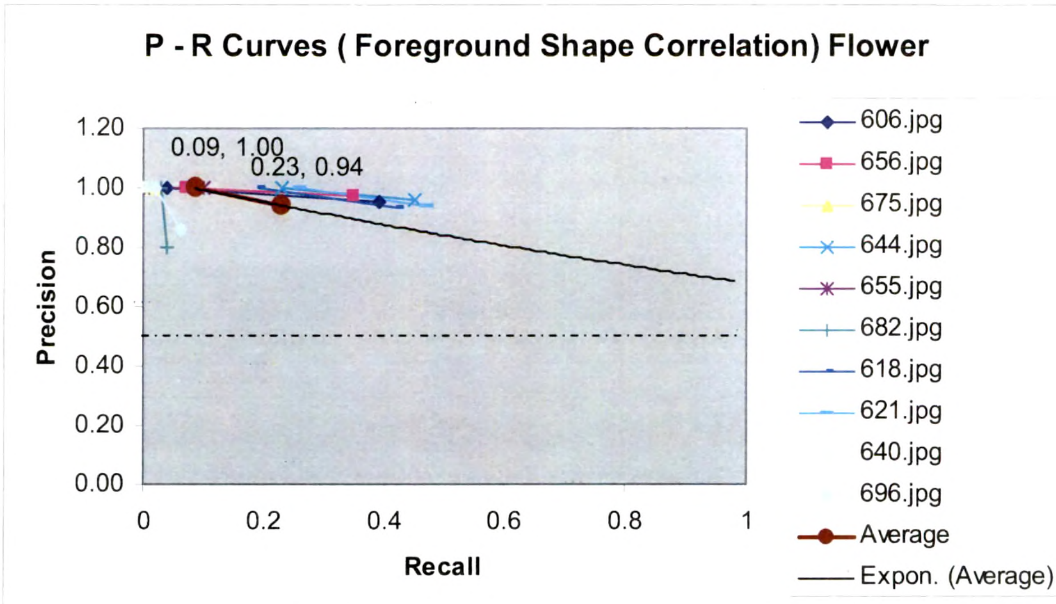


Figure 81. P- R curves (Foreground shape correlation). Class- Flower.

Following points are observed:

- The P – R curves obtained are close to ideal P – R curves.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- Despite vast variations in foreground colors and illumination conditions, good Recall with good Precision is achieved for many sample queries.
- For all queries, Precision of 1.0 is achieved for reasonable Recall.
- Range of average performance measures for the class
  - 100 % of average Precision for 9 % of average Recall
  - 94 % of average Precision for 23% of average Recall
  - Giving only 6 % of fall in average Precision to raise average Recall by 14 %
- The exponentially extended trend line is well above average Precision = (0.5) line implies good performance measures for images of the class.

6.8.2.1 Query Response Example

Figure 82 shows query response of a flower image with similarity cut-off 60 giving 34 flower images based on shape comparison. It should be noted that for same query image, whole image color code based approach retrieves maximum of 4 flower images whereas foreground color code based approach retrieves only the query image even for lowest similarity cut-off. (Table 11 and Table 18 respectively.)

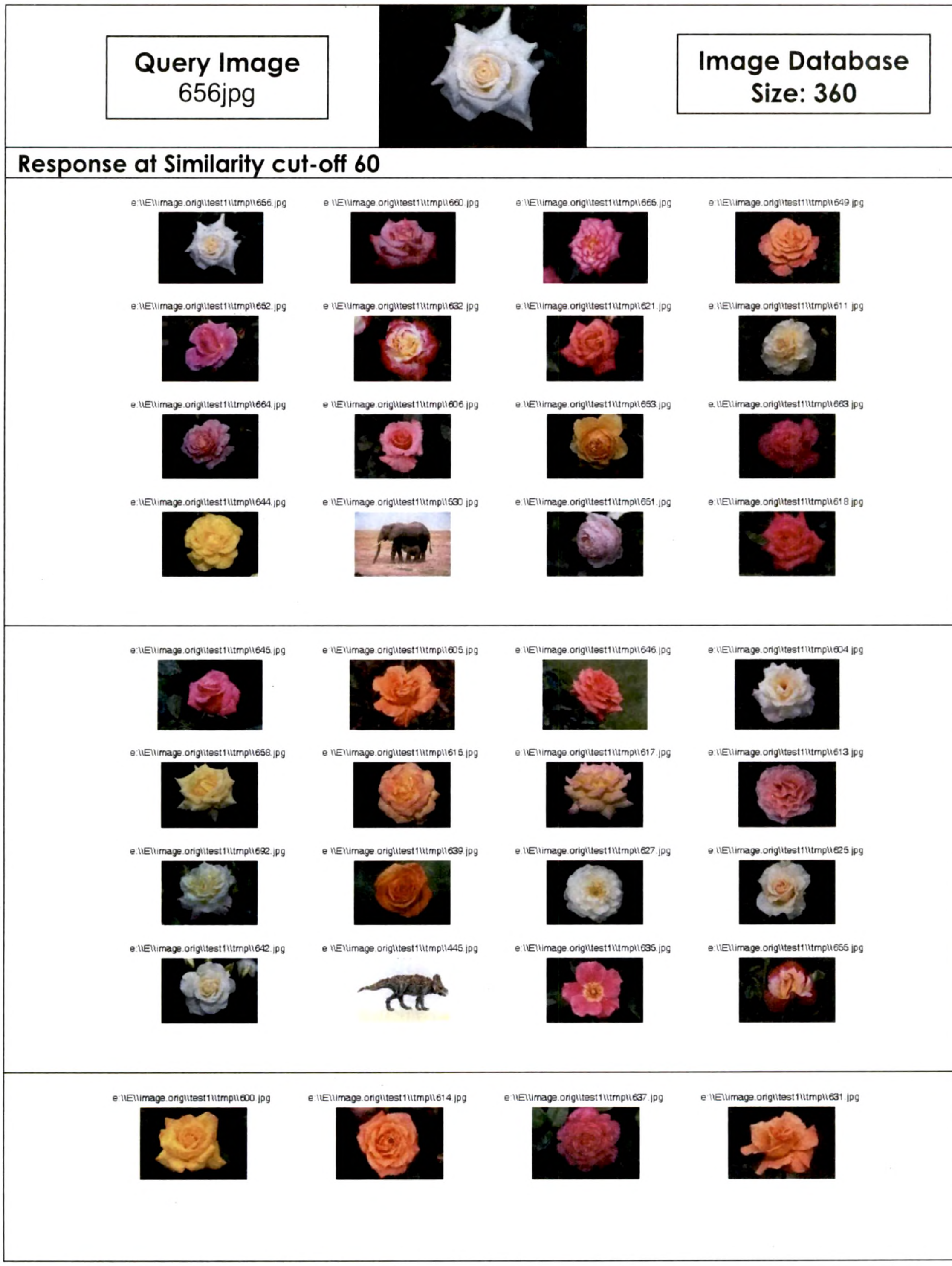


Figure 82. Query response of a flower image at similarity cut-off 60. (FG shape correlation)

6.8.3 Discussion

- The method is very sensitive to the shape of the foreground. Foreground object shape altering regions affect the performance of the method very adversely.
- The method gives very good results for images where foreground is not containing attached unwanted regions. E.g. images of ALOI database, images of class flower and class bus of SIMPLIcity [Wang, 2001] [SIMPLIcity, on line] database. The method may not perform equally well for the images like those of BSDB [Fowlkes, on line] [Martin, 2001].
- Relaxed similarity cut-off ends up in poor Precision. Recommended similarity cut-off is above 60% for better performance.
- Shape matching being a stricter constraint, relatively higher Precision and lower Recall are observed for the method.
- The shape correlation technique has been applied for face region matching for the purpose of similar-face image retrieval.

6.9 Foreground Color Codes & Foreground Shape Based CBIR

The proposed method compositely exploits two foreground features – shape and color codes. The weight proportion of these two features in the similarity measures is selectable by the user. Thus, the composite similarity measure signifies the proportionate emphasis of user's search criteria. The normalized unsegmented foreground region and foreground color codes have been utilized as the features for the image comparison. The method specific steps, replacing Step 3 & Step 4 of Algorithm 4, Section 6.5 are:

Step 3: Read (or extract) foreground color code features of given query image.

Read (or extract) normalized unsegmented foreground region features for the query image. Call it Rq.

Step 4: For every image-feature-file of target folder,

Read corresponding foreground color code features of the image-feature-file of target folder.

Calculate (dis)similarity_index $_i$ = $\sum abs(h_{qj} - h_{ij})$, for $1 < j <=$ number of bins, Where,

h_{qj} indicates j^{th} bin of normalized histogram of color codes for the query image

h_{ij} indicates j^{th} bin of normalized histogram of color codes for i^{th} image of database

Read normalized unsegmented foreground region features of the image-feature-file of target folder. Let us call it Rd_i.

Calculate correlation coefficients of Rq & Rd_i.

Find the significant correlation coefficient.

Calculate (dis)similarity_index1$_i$ = 100 – abs (significant correlation coefficient of Rq & Rd_i) * 100

Read Foreground_Colorcode_weight

Calculate composite (dis)similarity index as

(dis)similarity_index$_i$ = (Foreground_Colorcode_weight*(dis)similarity_index) + ((1.0 - Foreground_Colorcode_weight) *(dis)similarity_index1)

Algorithm 8. Foreground color codes & foreground shape based image retrieval.

6.9.1 Performance Evaluation

The performance of the method for different combinations of weights of foreground color code and foreground shape correlation in composite similarity index is tabulated for an image (455.jpg [Wang, 2001] [SIMPLIcity, on line]) of Dinosaur class is shown in Table 22. The respective P – R curves are presented in Figure 83.

Table 22. Precision, Recall & F –measure for different proportionate weights at different similarity cut-offs. (Foreground Color codes & foreground shape correlation).

Similarity cut-off for **455.jpg**	% Weight of FG CC in Similarity Index	Retrieved relevant images - rr	total retrieved images - total	Recall r = rr / Total	Precision p = rr / total	F measure
Total relevant images in the database, Total = 100						
50	0	29	82	0.29	0.35	0.32
60		7	17	0.07	0.41	0.12
70		1	1	0.01	1.00	0.02
50	10	29	46	0.29	0.63	0.40
60		3	5	0.03	0.60	0.06
70		1	1	0.01	1.00	0.02
50	20	26	38	0.26	0.68	0.38
60		3	3	0.03	1.00	0.06
70		1	1	0.01	1.00	0.02

Table 22 (Contd.). Precision, Recall & F –measure for different proportionate weights at different similarity cut-offs. (Foreground Color codes & foreground shape correlation).

Similarity cut-off for **455.jpg**	% Weight of FG CC in Similarity Index	Retrieved relevant images - rr	total retrieved images - total	Recall r = rr / Total	Precision p = rr / total	F measure
Total relevant images in the database, Total = 100						
50	30	25	34	0.25	0.74	0.37
60		6	7	0.06	0.86	0.11
70		1	1	0.01	1.00	0.02
50	40	26	34	0.26	0.76	0.39
60		8	9	0.08	0.89	0.15
70		1	1	0.01	1.00	0.02
50	50	27	36	0.27	0.75	0.40
60		12	15	0.12	0.80	0.21
70		2	2	0.02	1.00	0.04
50	80	29	35	0.29	0.83	0.43
60		23	28	0.23	0.82	0.36
70		12	14	0.12	0.86	0.21
50	100	30	38	0.3	0.789474	0.43
60		21	26	0.21	0.807692	0.33
70		16	20	0.16	0.8	0.27

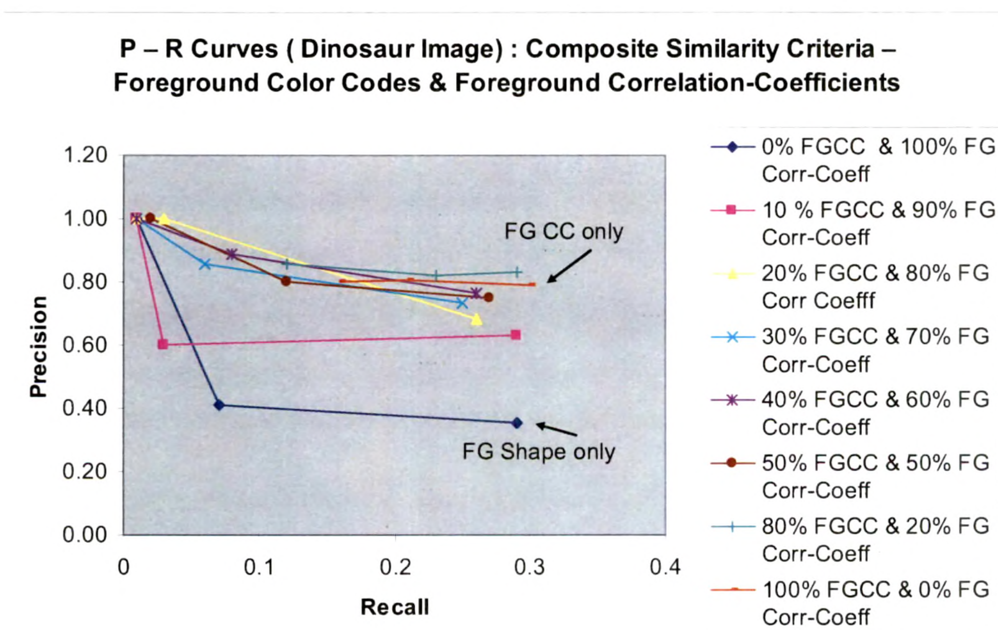


Figure 83. P- R curves for different proportionate weights of Foreground color codes & foreground shape correlation.

The suitable proportion of weight for best retrieval performance is image specific. The user is given a choice of selecting the weight and altering the proportion if required for successive retrievals. The Precision and Recall for two images of flower given as queries with 70% - 30% & 30%-70% weight proportion (Foreground CC & Foreground shape correlation) has been computed in Table 23. The high Precision is noteworthy.

Table 23. Precision, Recall & F –measure for two different proportionate weights at different similarity cut-offs. (Foreground Color codes & foreground shape correlation).

Query Image	Similarity cut-off	% Weight of FG CC in Similarity Index	Retrieved relevant images - rr	total retrieved images - total	Recall r = rr / Total	Precision p = rr / total	F measure = 2/(1/ p + 1/r)
Total relevant images in the database, Total = 100							
606.jpg 	40	70	28	28	0.28	1.00	0.44
	50		16	16	0.16	1.00	0.28
	60		14	14	0.14	1.00	0.25
	70		3	3	0.03	1.00	0.06
	40	30	35	35	0.35	1.00	0.52
	50		18	18	0.18	1.00	0.31
	60		12	12	0.12	1.00	0.21
	70		4	4	0.04	1.00	0.08
644.jpg 	40	70	19	30	0.19	0.63	0.29
	50		12	19	0.12	0.63	0.20
	60		10	11	0.1	0.91	0.18
	70		7	7	0.07	1.00	0.13
	40	30	18	24	0.18	0.75	0.29
	50		14	14	0.14	1.00	0.25
	60		11	11	0.11	1.00	0.20
	70		6	6	0.06	1.00	0.11

6.9.1.1 Query Response Examples:

Figure 84 and Figure 85 show respective retrieval results for a flower image with 20 % and 10 % weight of foreground color codes in the composite similarity index. The reduction in weight of foreground color codes and corresponding increase in the weight of foreground shape correlation results into retrieval of more flower images, not necessarily while flower images. Image retrieval with same query image for foreground color code method (100 % weight of foreground color codes), only the query image gets retrieved (Table 11). The reduction of similarity cut-off results into retrieval of more images as shown in Figure 86 & Figure 87.

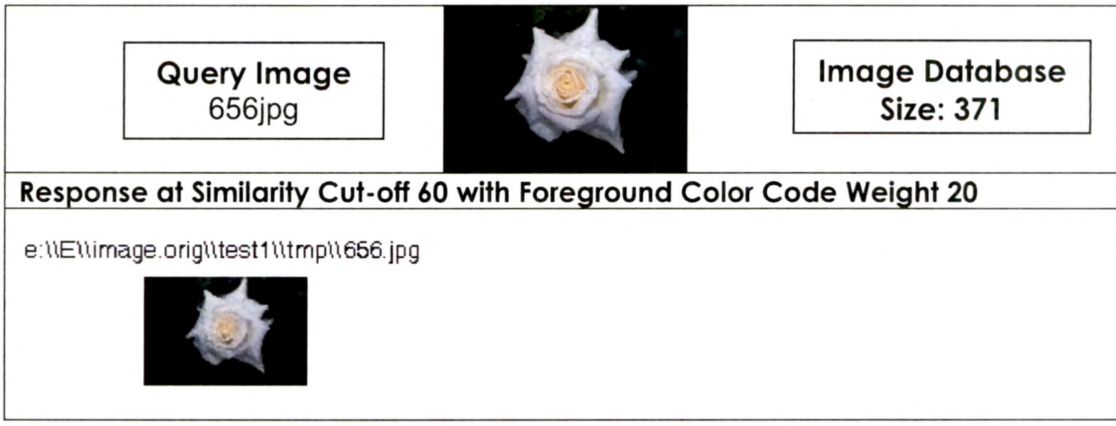


Figure 84. Query response of a flower image at similarity cut-off 60 with FG CC weight 20. (FGCC & FG shape correlation)

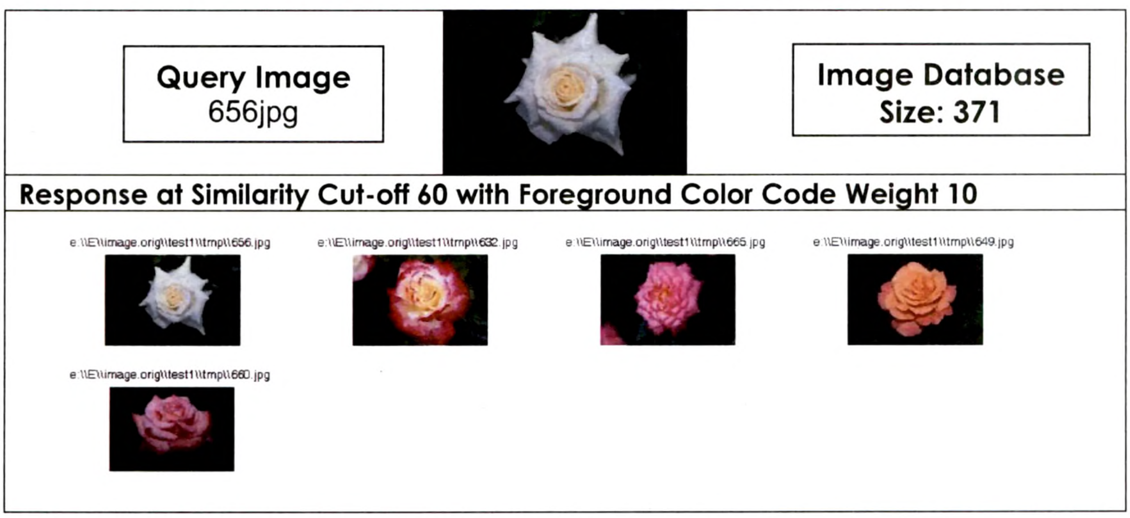


Figure 85. Query response of same flower image at similarity cut-off 60 with FG CC weight 10. (FGCC & FG shape correlation)

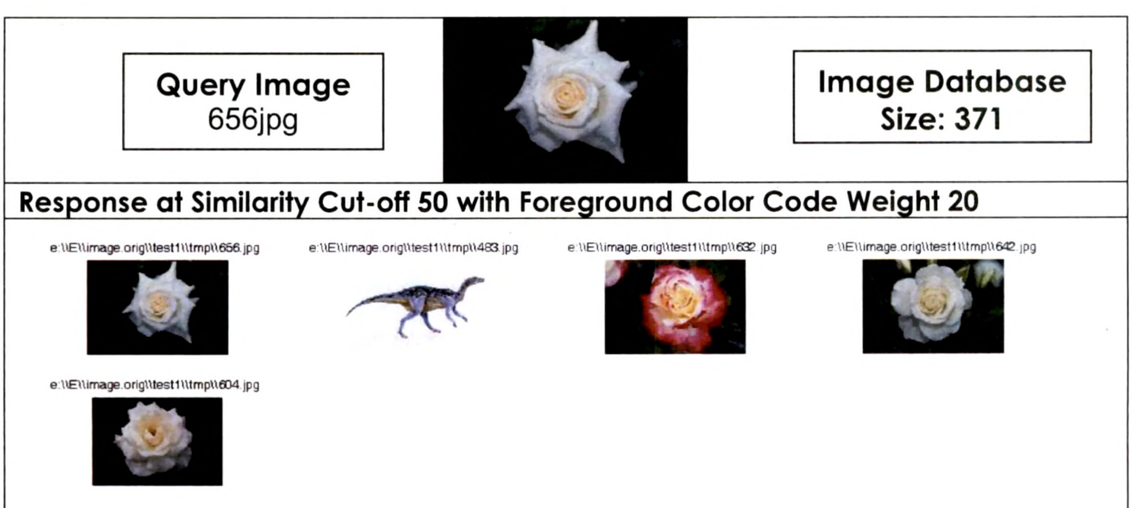


Figure 86. Query response of same flower image at similarity cut-off 50 with FG CC weight 20. (FGCC & FG shape correlation)

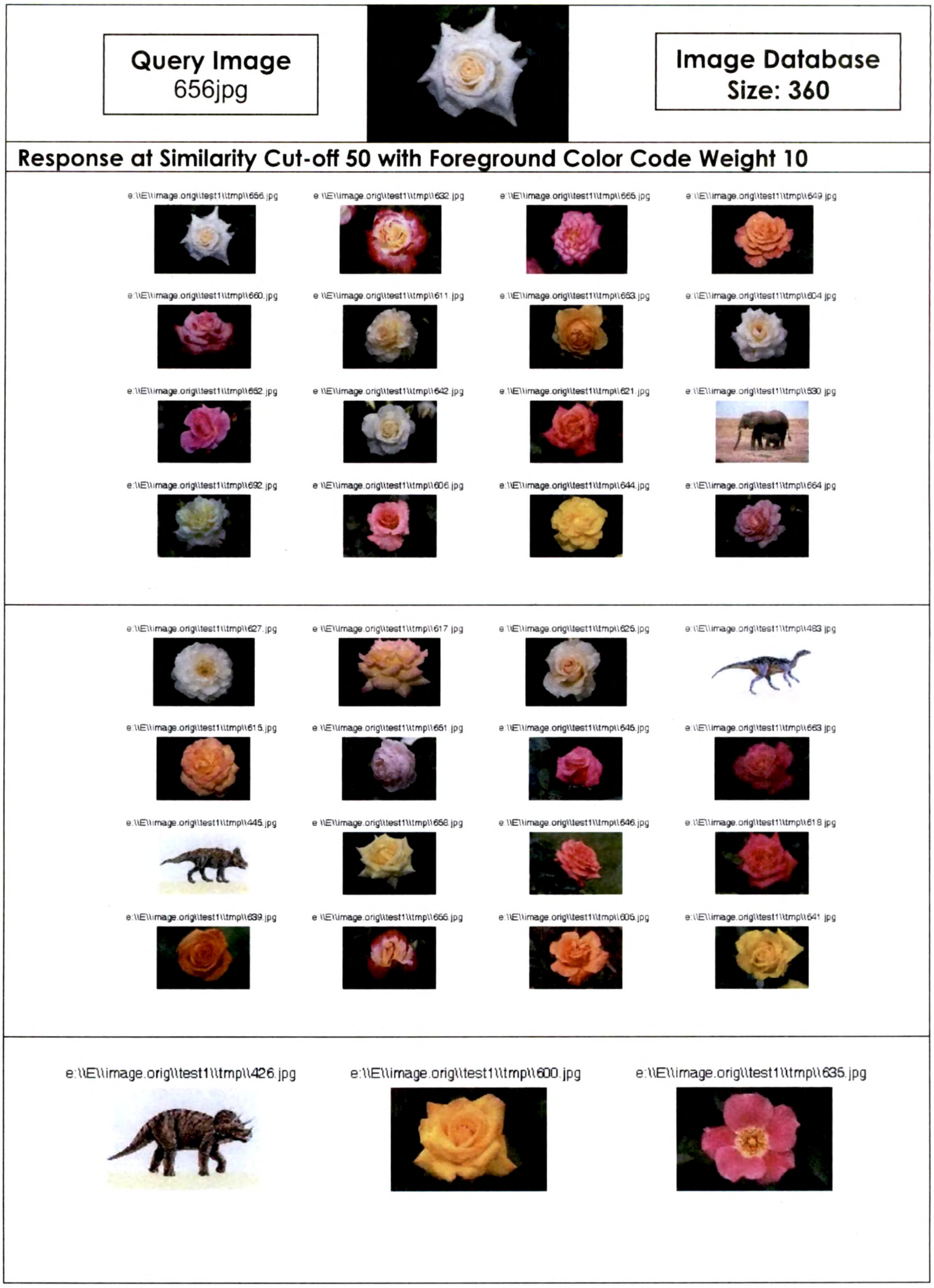


Figure 87. Query response of same flower image at similarity cut-off 50 with FG CC weight 10. (FGCC & FG shape correlation)

6.9.2 Discussion

- The method exploits advantages of all previously proposed methods. The foreground based approach eliminates unwanted, major contributing background and related features enabling object based search with additional constraints of foreground shape and colors.
- The selectable proportion of weight of foreground color codes and foreground shape ends up in good performance of the system.

6.10 Comparisons - Query Responses of Various Algorithms

The section provides comparison of query responses of various proposed method of image retrieval for same query images. The first example is for comparison of response of various methods for a flower image of SIMPLIcity [Wang, 2001] [SIMPLIcity, on line] image database whereas the second example is for the ALOI image data base [ALOI, on line] [Geusebroek, 2001]. Typical characteristics of the databases are described in Section 6.4.

6.10.1 Example 1 - SIMPLIcity image database [Wang, 2001] [SIMPLIcity, on line]

Figure 88 to Figure 91 are the respective query responses of proposed four methods for same query-image with same similarity cut-off of 60. The query response with whole image color codes based retrieval gives 2 similar flower images shown in Figure 88. The response of same query image with foreground based color code approach yields 15 similar – red flower images as shown in Figure 89. The response with foreground shape correlation method is shown in Figure 90 indicates retrieval of 39 flower images (not only red) and 2 non-flower images. The foreground color codes and foreground shape based approach with 30% weight to foreground color method yields response shown in Figure 91 giving 12 similarly shaped red flower images.

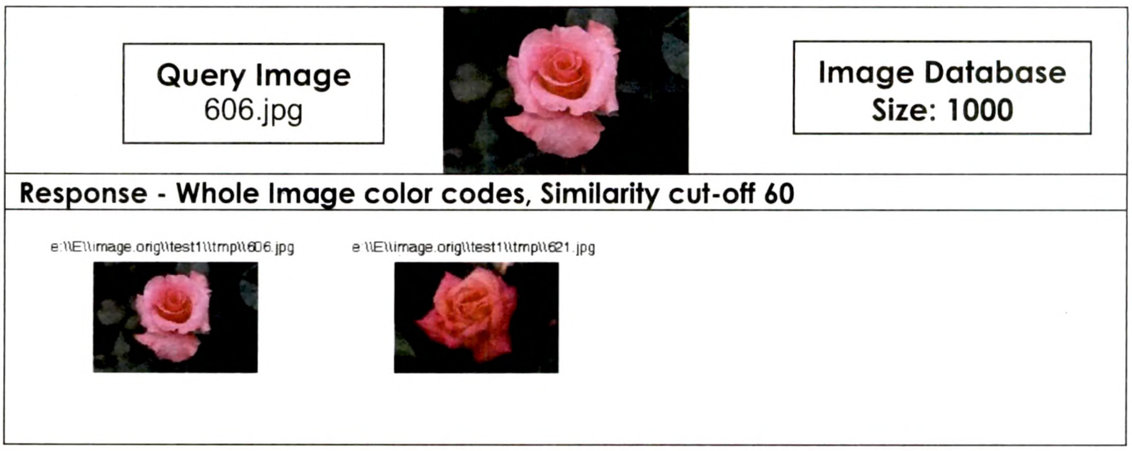


Figure 88. Query response of a flower image at similarity cut-off 60. (Whole image color codes).

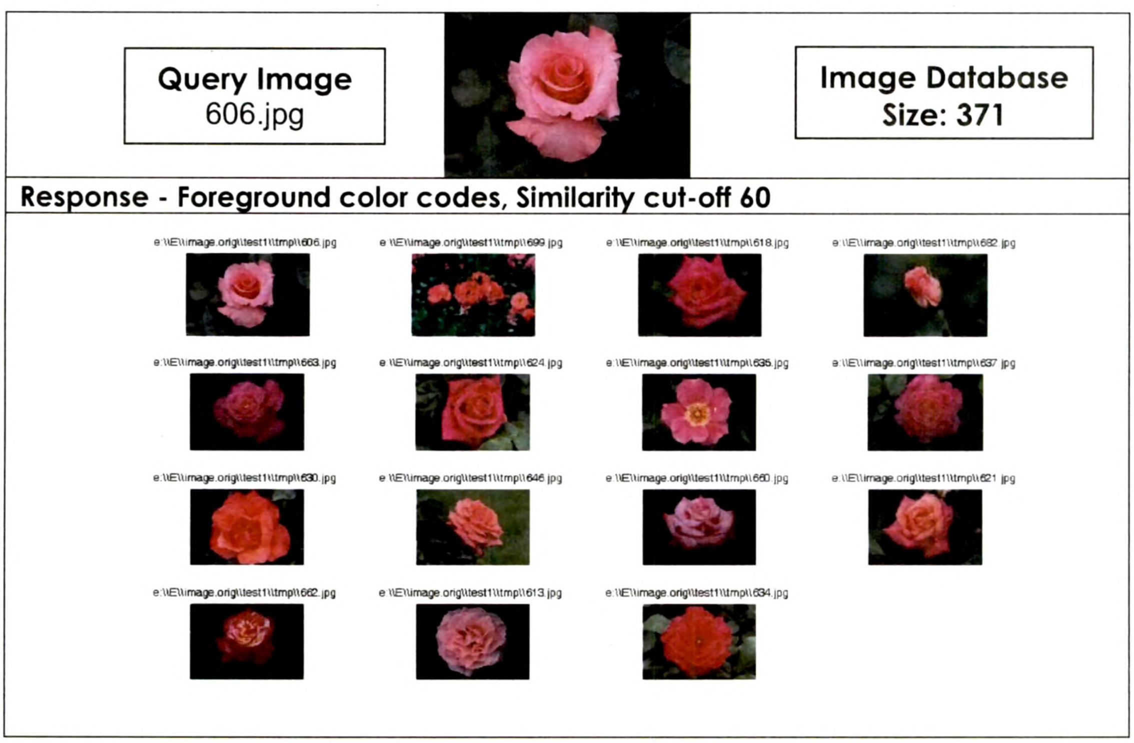


Figure 89. Query response of same flower image at similarity cut-off 60. (Foreground color codes).

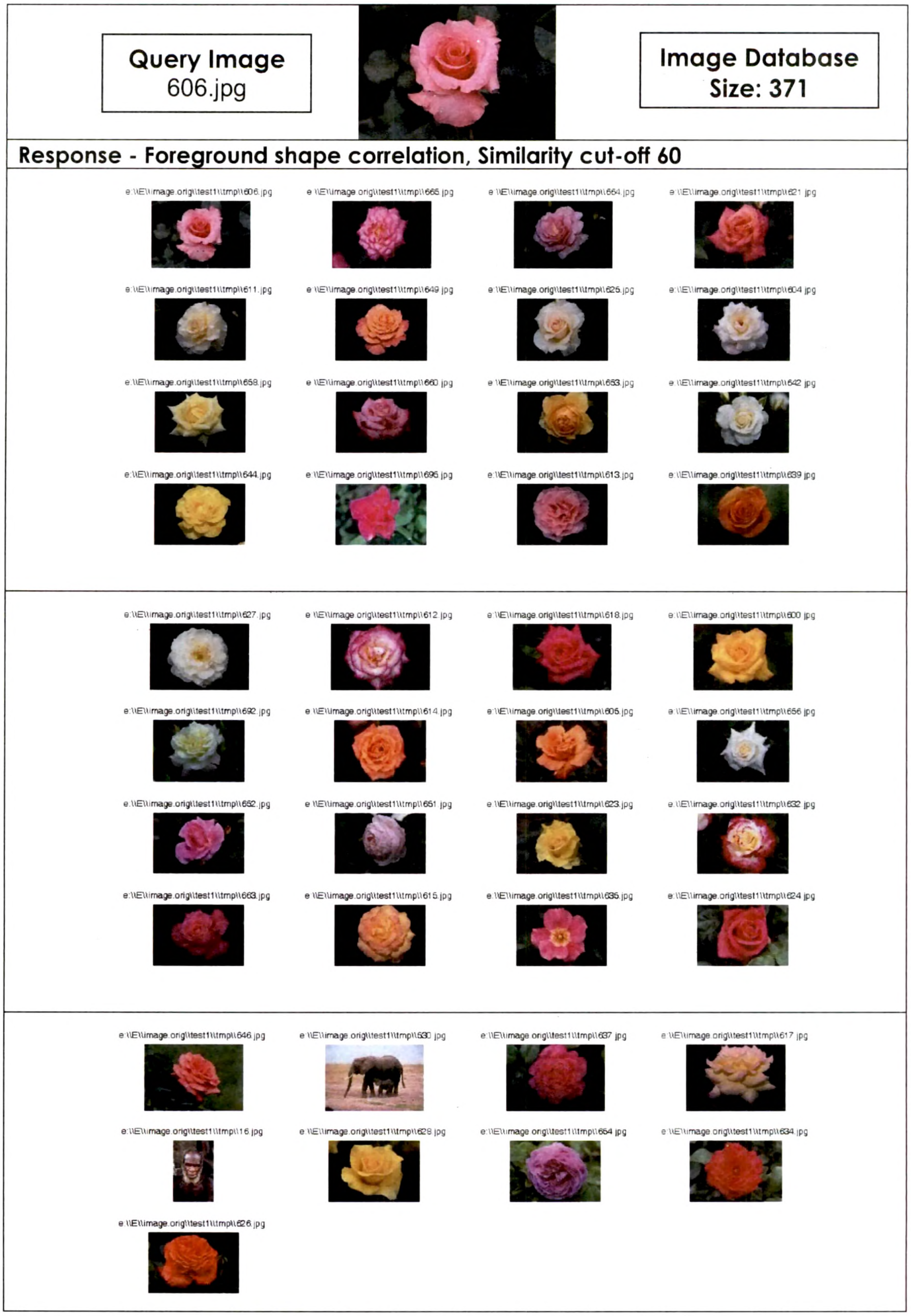


Figure 90. Query response of same flower image at similarity cut-off 60. (Foreground shape correlation).

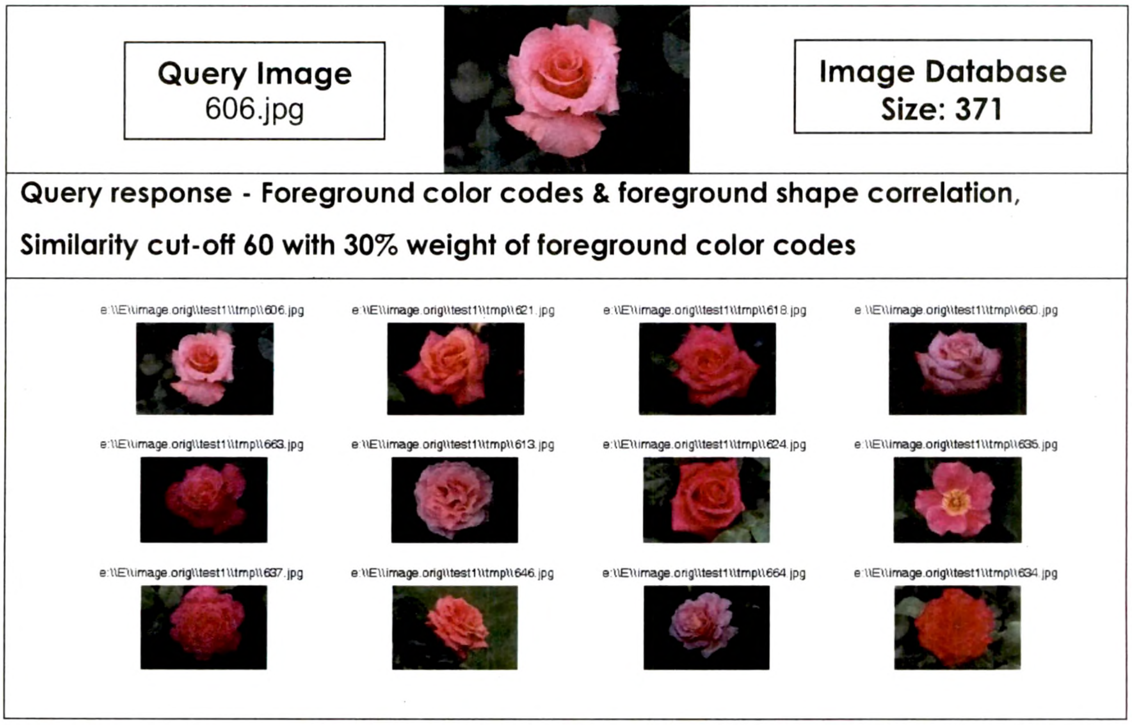


Figure 91. Query response of same flower image at similarity cut-off 60 with 30% weight of FGCC. (Foreground color codes & foreground shape correlation).

6.10.2 Example 2 - ALOI image database [ALOI, on line] [Geusebroek, 2001]

The effect of illumination changes and object view point variations on image retrieval has been illustrated with following query responses of various methods for same query image – a toy duck for similarity cut-off of 70. The major portion of the background in the image causes poor Precision for whole image color code method as shown in Figure 92. The foreground color code based approach improves the Precision by giving yellow / white colored toy images as the response as shown in Figure 93. The foreground shape based method for retrieval gives good Recall and Precision with duck toys ranked higher, as shown in Figure 94. The foreground based composite approach with color codes and shape correlation with 30% weight of foreground color codes give the best performance as shown in Figure 95.

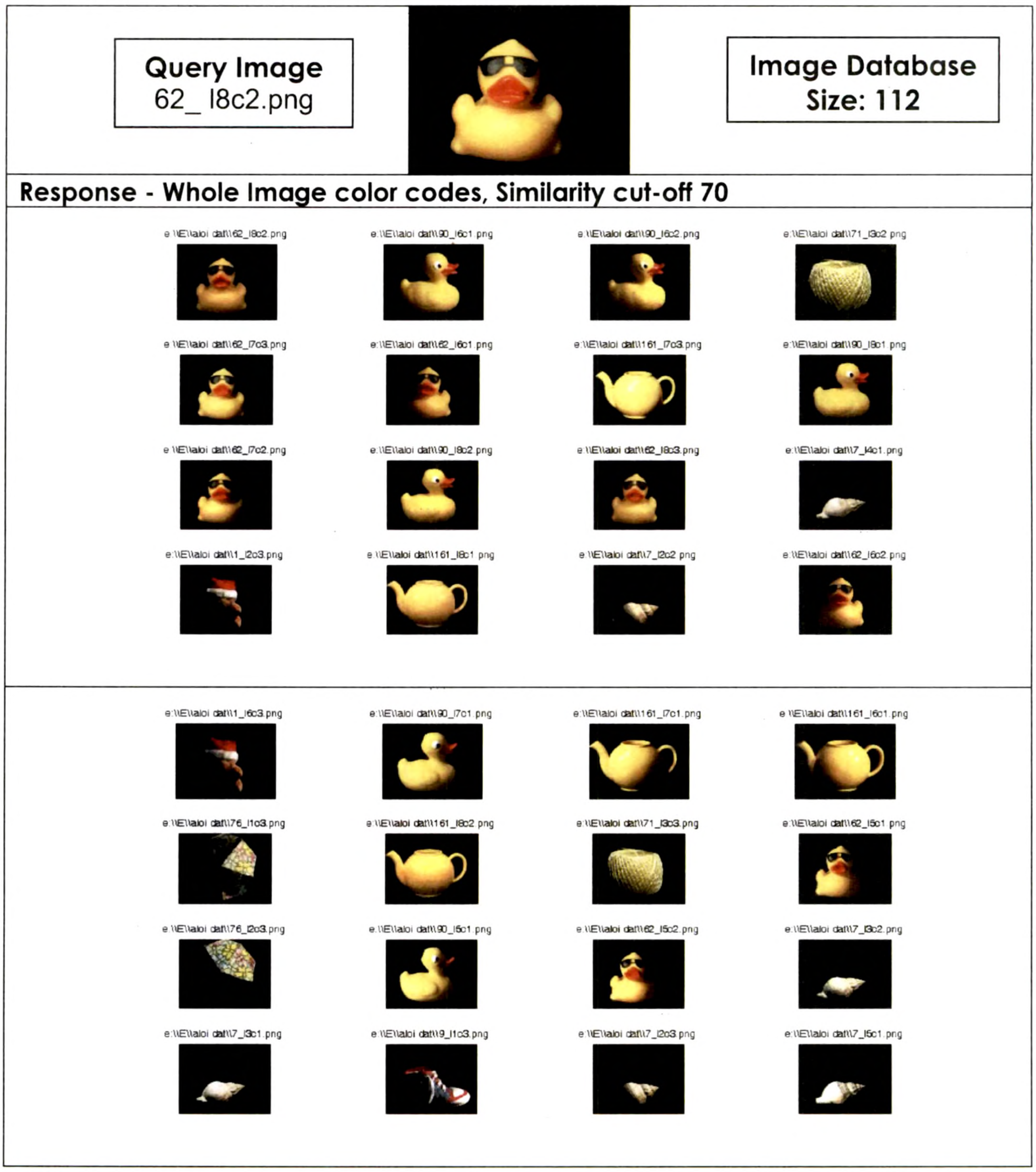


Figure 92. Query response of an ALOI image at similarity cut-off 70. (Whole image color codes).

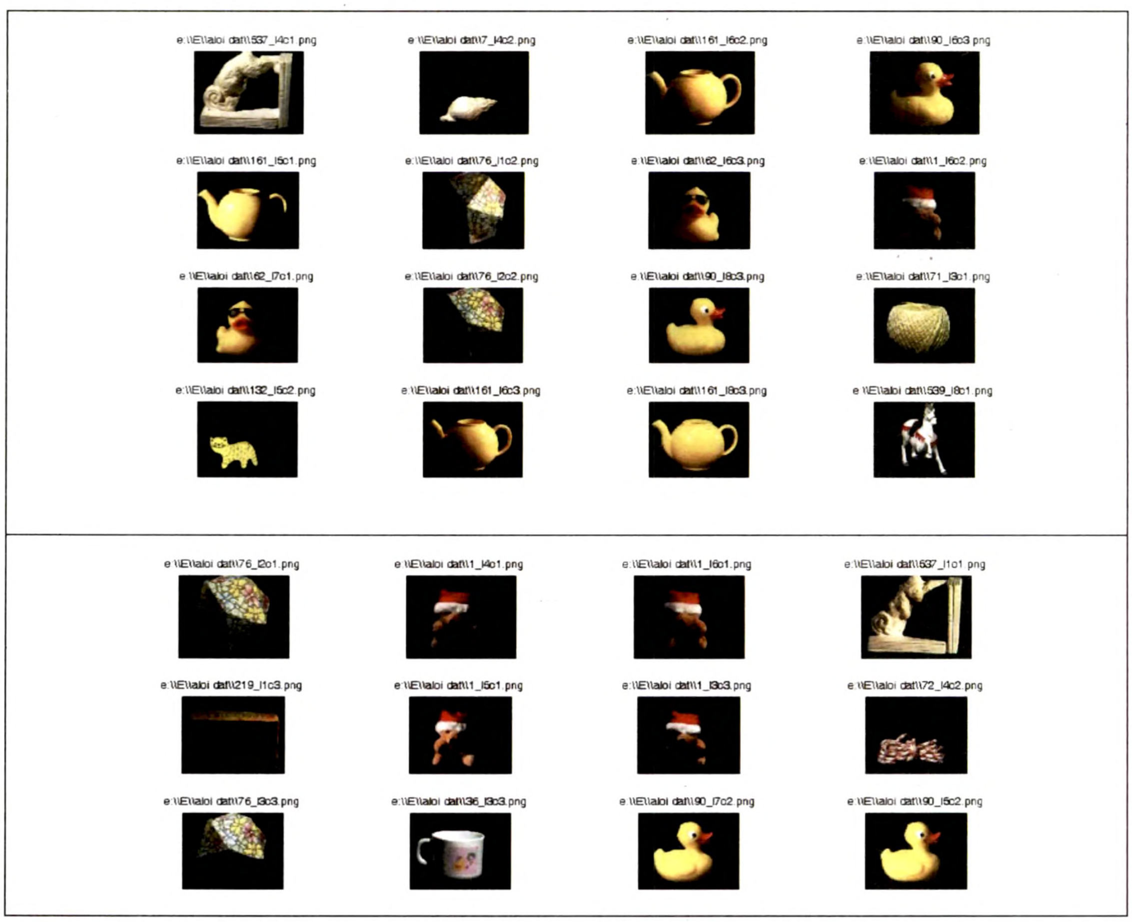


Figure 92 (Contd.). Query response of an ALOI image at similarity cut-off 70. (Whole image color codes).

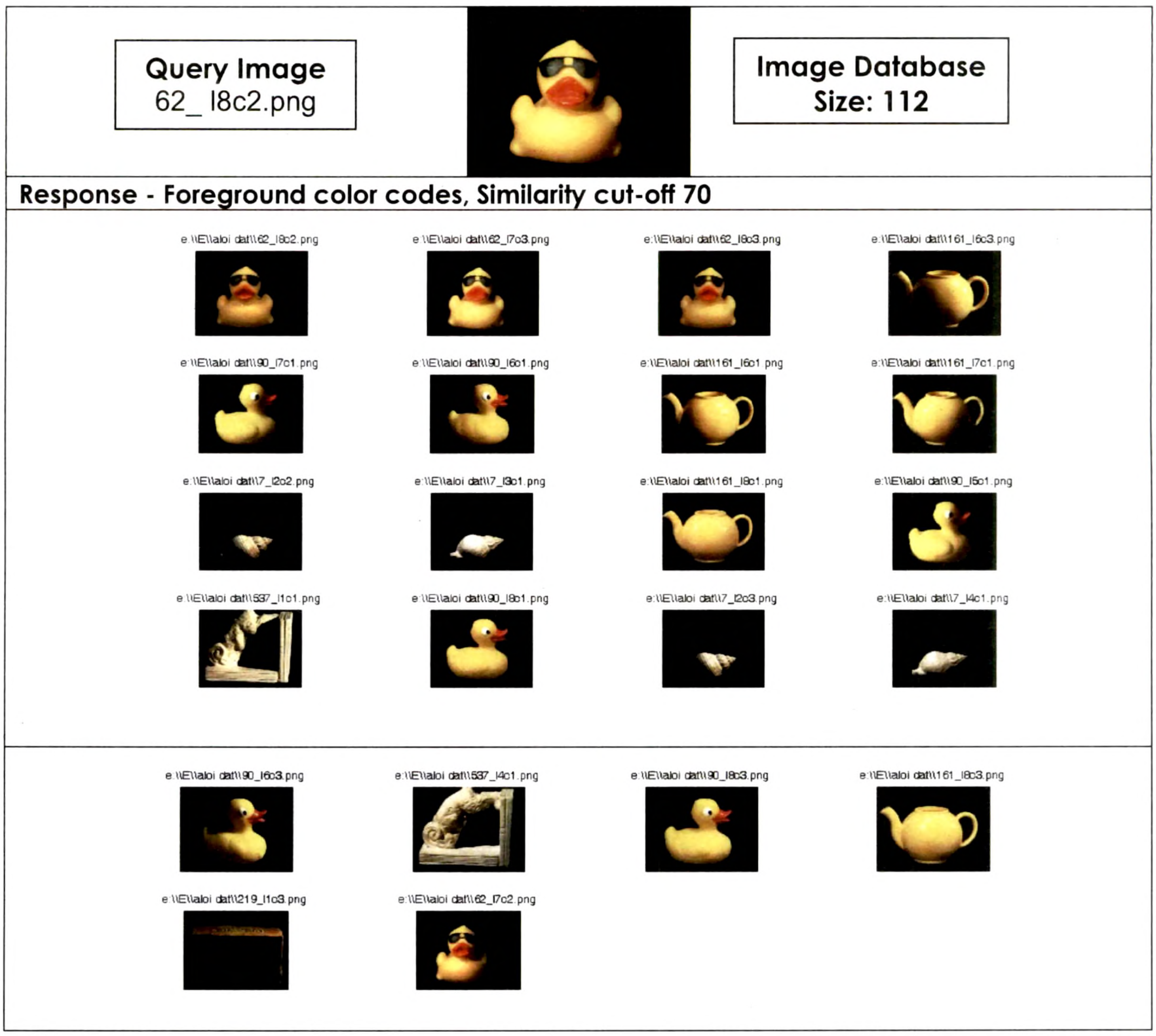


Figure 93. Query response of same ALOI image at similarity cut-off 70. (Foreground color codes).

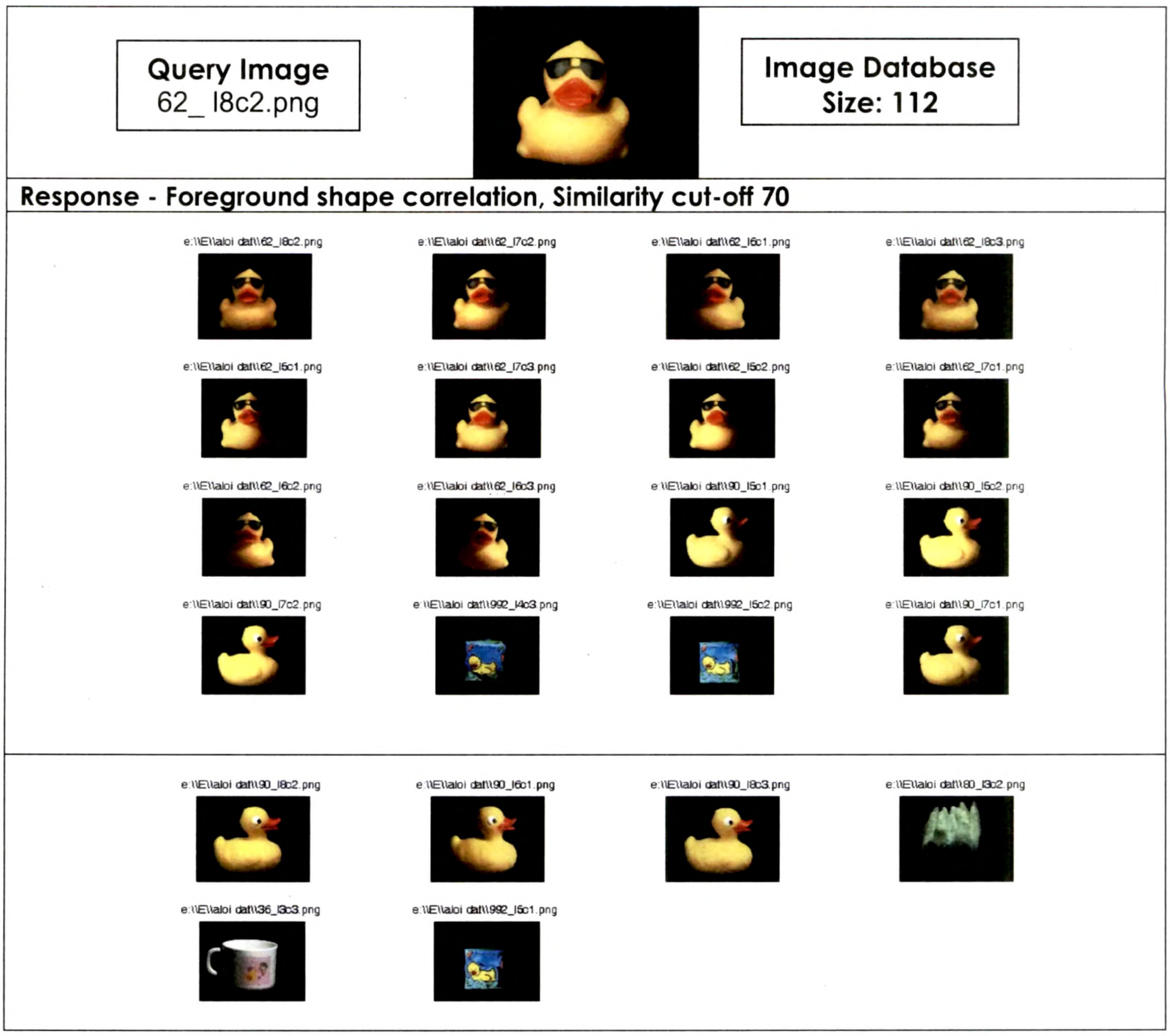


Figure 94. Query response of same ALOI image at similarity cut-off 70. (Foreground shape correlation).

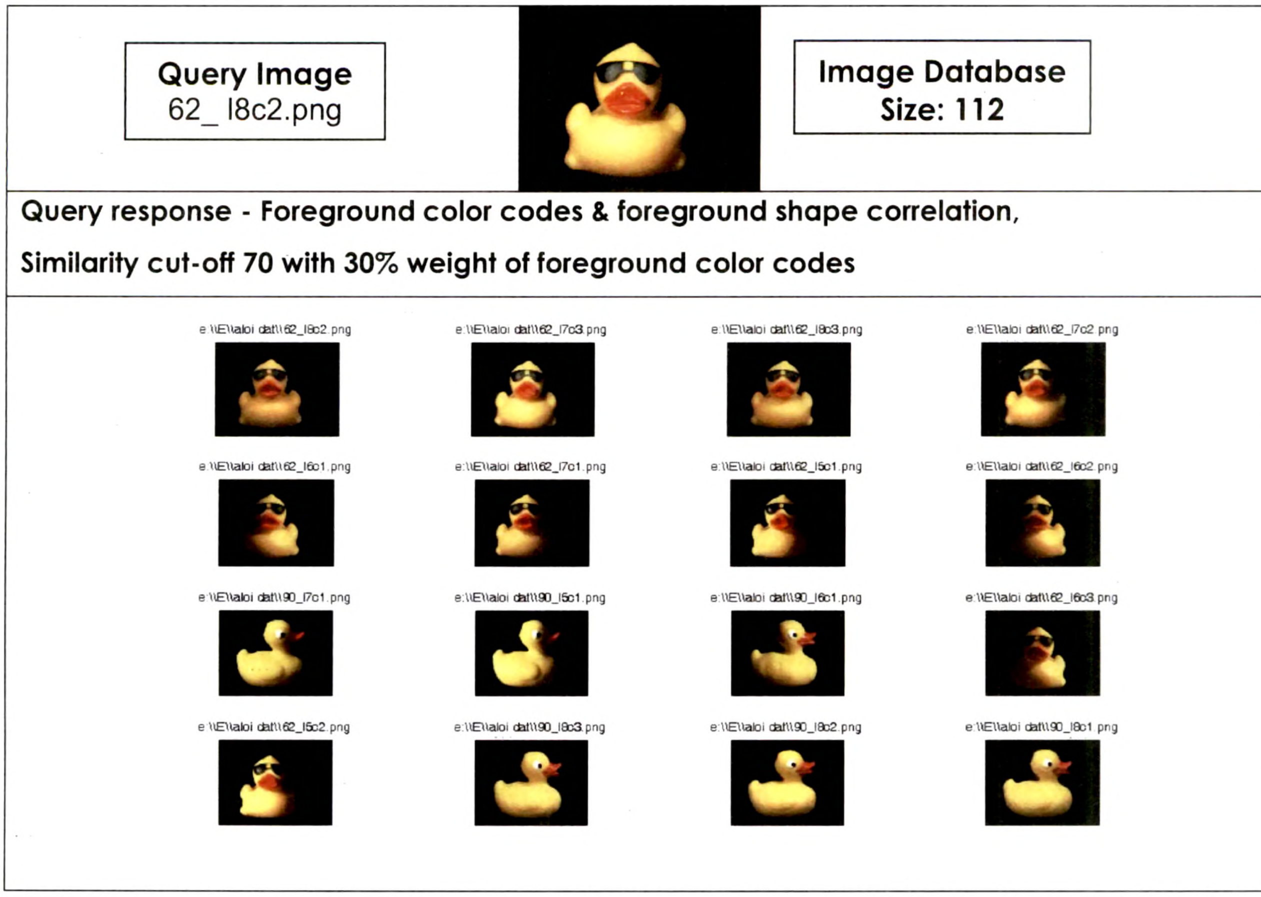


Figure 95. Query response of same ALOI image at similarity cut-off 70 with 30% weight of FGCC. (Foreground color codes & foreground shape correlation).

6.10.3 Discussion

- The whole image color code based approach is well suitable for finding images having similar foreground-background color code distribution. High Recall values are possible because of broader color descriptors. The method faces conventional limitations because of not considering shapes or any other regional features.
- The foreground region based approaches enable foreground object based image search by considering foreground color codes and foreground shape correlation. The foreground color code based approach permits retrieval of foreground shape variant similar images. The foreground shape correlation has been a stricter comparison and very sensitive to extracted foreground shape.
- The composite similarity measure of foreground color codes & foreground shape performs well for majority of query images.

6.11 Application Specific CBIR - Similar Face Image Retrieval

This section is an application of proposed methods for application-specific CBIR to retrieve similar face images from images containing complex background. The feature extraction phase consists of face region extraction technique based on prominent boundaries detection based foreground separation. The similarity measure for face regions is the shape correlation comparison as described in Section 6.8. The high success ratio of precise face region extraction for complex backgrounds and illumination variations has been exploited for shape correlation based similarity comparison for image retrieval.

6.11.1 Face Extraction from Images Containing Complex Background

The section proposes novel method for human frontal face extraction from color images characterized by uncontrolled illumination conditions for image capturing and complex backgrounds. The method incorporates stationary Haar wavelet transform & proximity influence for prominent boundaries detection and watershed transform, proximity influence & morphological operations to separate foreground / background along with region and color attributes for human face extraction. The method exploits redundancy by coalescing local color cues of all color channels to emphasize reliable processing to precisely detect the human face by avoiding under-segmentation and reducing over-segmentation & artifacts. The method has been tested on face-image collection of standard database and on images captured by an amateur photographer for various complex backgrounds having diversified textures, varied illumination conditions and multiple background objects. The presented results show the effectiveness of the method for frontal face extraction, proving it suitable as an input to applications like digital album catalogue, content based image retrieval, face recognition and facial expression recognition.

First well-thought out algorithm for image segmentation would be a watershed algorithm [Beucher, 1979]. The watershed algorithm has inherent characteristic of finding local minima – catchments basins producing over-segmentation of regions and introducing artifacts. Hence, watershed transform cannot be applied directly on images having textures, texture or smooth color tone variations e.g. natural images. Any filtering-preprocessing before applying watershed algorithm results into loss of information introducing either leaks in the boundaries or spurious boundaries leading to improper segmentation. Hence, other techniques required to be combined with watershed algorithm to overcome short-comings of watershed algorithm exploiting advantages of the same. So has been done in the proposed method.

The face extraction is a process of isolating face region from all other regions. The performance of the face extraction is challenged by characteristics like illumination variations, shadows, skin-colored other regions, face-shaped other regions, multiple objects, diversified indoor & outdoor background textures, wide range of face skin colors and hair colors, different hair styles, different face orientations, different image resolutions along with aforesaid image segmentation issues as image segmentation being the inevitable first step of the process.

The issue of extraction of human face from images captured in uncontrolled illumination conditions having complex & non-uniform background has been addressed in the proposed method by performing proper segmentation followed by foreground / background separation and face region extraction. The image characteristics - illumination variations and diversity & variations in the background textures impose challenges at the segmentation and face extraction phase. The proposed method enforces reliable processing of local color cues of all color and gray channels for forming continuity preserving prominent boundaries incorporating Stationary Haar wavelet at various levels. The prominent boundaries, proximity influence and watershed transforms are compositely used for revealing foreground from the image. This foreground may consist of human face, hair and attached regions due to complex & non-uniform background. Various region attributes along with color attributes are used to extract the face. The method overcomes issues of under-segmentation by precise processing of low level cues generating well localized, delineated leak-free boundaries which are further categorized as prominent boundaries encompassing visually prominent regions in the image. The method minimizes over-segmentation & artifacts producing proper segmentation needed for face extraction in majority of the cases containing illumination variations. The incorporation of Stationary Haar decomposition at various levels makes method suitable for hierarchical framework. The performance of the method has been evaluated on face images of standard dataset Caltech 101 [Caltech, on line] [Fei-Fei, 2004].

6.11.1.1 The Method

The proposed method exploits redundancy by finally coalescing local cues of R, G, B and Gray color channels for prominent boundaries detection and for formation of composite watershed regions utilized for face extraction.

The region attributes considered for determining the face region are defined in the method regionprops of Matlab 14 as follows: Orientation - The angle (in degree) between the x-axis and the major axis of the ellipse that has the same second-moments as the region. Extent – The portion of the pixels in the bounding box that are also in the region. Eccentricity – Measured for the ellipse that has the same second-moments as the region. It is the ratio of the distance the foci of the ellipse and its major axis length.

The steps involved for the face extraction are:

Step 1: Apply foreground extraction Step 1 to Step 10 of Algorithm 3, Section 5.2.

Step 2: For all regions of foreground,

Exclude small regions.

For remaining regions,

Mark a region as face region if orientation > 70, Eccentricity > 0.3, extent < 0.95, axis _ratio (Minor axis length / Major axis length) > 0.4 and if region contains skin color. Mark image category as face.

Step 3: Map face region on the image to extract face image.

Algorithm 9. Face extraction from images containing complex background.

The thresholds are empirically determined to reflect shape attributes of face.

6.11.1.2 Results

The method has been tested on test set consists of 115 face-images of Caltech 101 face dataset [Caltech, on line] [Fei-Fei, 2004] comprising of faces of 15 persons and other high resolution images captured by an amateur photographer. The test set images are selected to cover various illumination variations and backgrounds. The images containing mustache and bearded face are excluded from the test set. The Caltech dataset [Caltech, on line] [Fei-Fei, 2004] found most appropriate as the data set because it contains color face images of medium size and reasonable resolution. The multiple images of persons have been captured at various indoor-outdoor places with various complex backgrounds under different illumination conditions generating shadows and illumination variations. Figure 96 illustrates results of various phases of face extraction incorporating two different levels of wavelet decomposition – level 1 and level 2. The prominent boundaries detected for Gray channel has been shown in Figure 96 (b). Various regions of segmented color channels have been shown in Figure 96 (c) to Figure 96 (f). The composite regions of segmented image are shown in Figure 96 (g). The watershed pixels constituting region isolating boundaries have been shown in Figure 96 (h). Figure 96 (i) and Figure 96 (j) corresponds to separated background and foreground respectively. The foreground is marked as black in the background image and background is marked as black in the foreground image. The extracted faces are finally shown in Figure 96 (k). In general, reduction of image dimension by a large factor may adversely affect the segmentation performance due to interpolated pixel color values. The unaffected result of face extraction for a size reduced high resolution image has been shown in Figure 97. Figure 98 illustrates unsuccessful face extraction due to improper segmentation because of extreme illumination variations on the face. The extracted faces of some of the images of test set have been shown in Figure 99. The typically picked up images contain distinctiveness like non-face skin color regions, other face-shaped regions, skin-colored hair, off-centered face, multiple background objects and most importantly illumination variations due to different lightning conditions at indoor-outdoor locations. Table 24 depicts the effectiveness and robustness of the method for successfully extracting faces for 82.6 % of the images of the test set.

6.11.1.3 Discussion

- The proposed method is novel for prominent boundaries, proximity influence, Stationary Haar Wavelet, used for generation of composite watershed regions for foreground separation that is combined with face-region & face-color attributes for frontal face extraction.
- The well localized and delineated continuity preserving prominent boundaries detected by precise and reliable processing of low level color cues of all color and gray channels form the basis of high (82.6 %) successful face extraction ratio for 115 test images of Caltech 101 [Caltech, on line] [Fei-Fei, 2004] dataset.
- The extraction of face has been tested on various images containing performance affecting characteristics like illumination variations, shadows, skin-colored other regions, face-shaped other regions, multiple objects, diversified indoor & outdoor complex-background textures, wide range of

face skin colors and hair colors, different hair styles, different face orientations etc. The stationary Haar wavelet decomposition at various levels, prominent boundaries & proximity influence avoids under-segmentation and reduces over-segmentation & artifacts – inherent characteristics of watershed transform.

- The method results are not affected due to interpolation operation involved in a size reduction of a high resolution image by a large factor.
- As shape and color of the face region is largely altered due to mustache & bearded, the method fails for face extraction of such cases. Similarly, a dark face segmenting shadow also produces ill results of face extraction.
- Still, precisely extracted faces with high performance ratio for variety of images proves the suitability and versatility of the method for applications like digital album catalogue, content based image retrieval, face recognition and facial expression recognition.

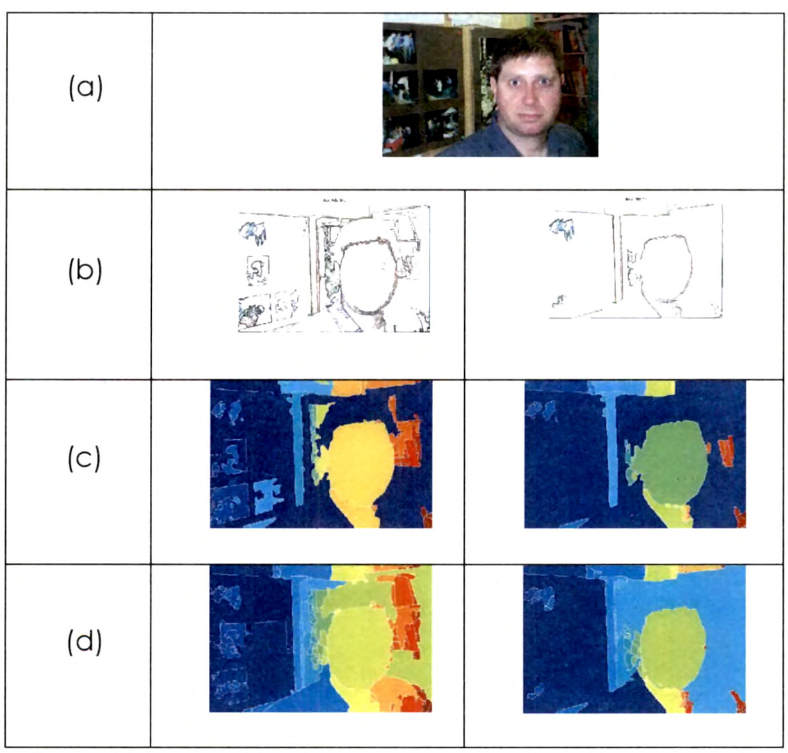


Figure 96. Various steps of face extraction. Left - stationary Haar wavelet decomposition at level 1. Right - stationary Haar wavelet decomposition at level 2. (a) Original image [Caltech, on line] [Fei-Fei, 2004]. (b) Detected prominent boundaries of gray channel. (c) Segmented regions of red color channel. (d) Segmented regions of green color channel.

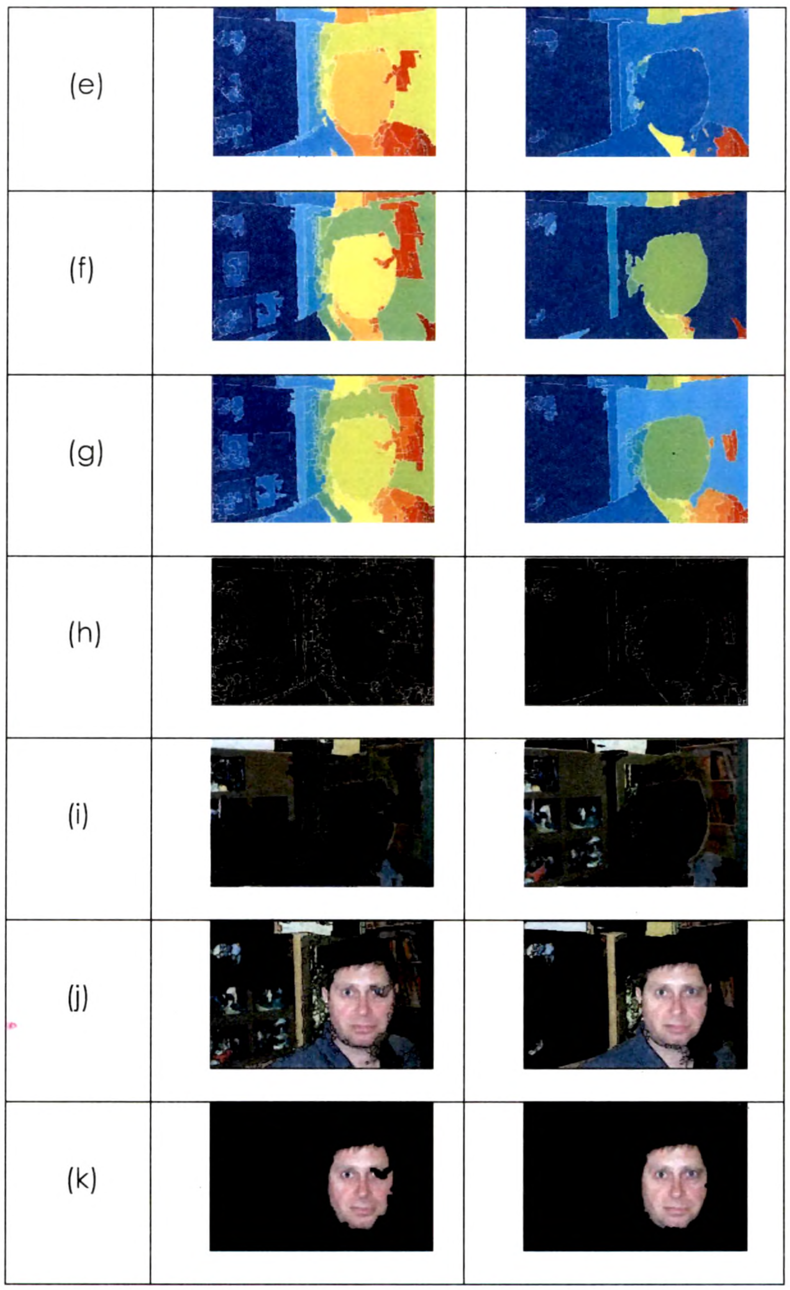


Figure 96 (Contd.). Various steps of face extraction. (e) Segmented regions of blue color channel. (f) Segmented regions of gray color channel. (g) Composite segmented regions. (h) Corresponding watershed pixels of (g). (i) Background. (j) Foreground. (k) Extracted face.

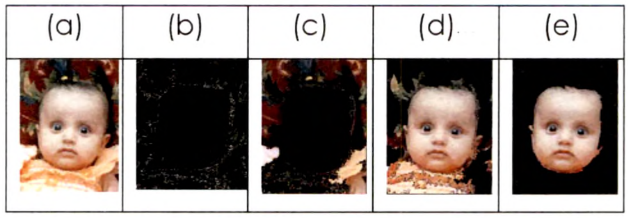


Figure 97. Face extraction in high resolution image reduced to 1/8th of the original size. (a) Original image. (b) Watershed pixels. (c) Background. (d) Foreground. (e) Extracted face.

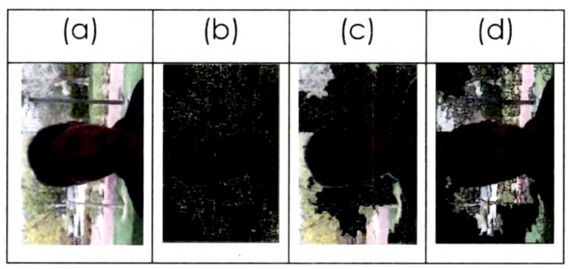


Figure 98. Example of unsuccessful face extraction. (a) Original image [Caltech, on line] [Fei-Fei, 2004]. (b) Watershed pixels. (c) Background. (d) Foreground.

Figure 99. Face extractions of various images with complex background and non-uniform illuminations. (a) Original images [Caltech, on line] [Fei-Fei, 2004]. (b) Watershed pixels. (c) Backgrounds. (d) Foregrounds. (e) Extracted face.

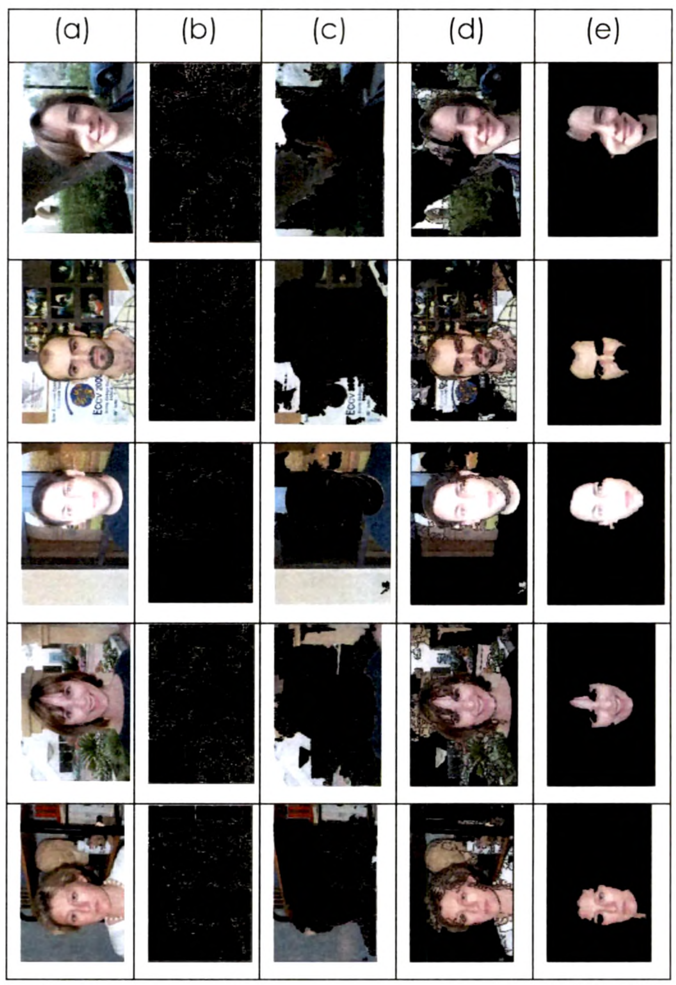
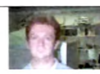
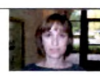
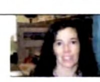
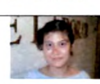


Figure 99 (Contd.). Face extractions of various images with complex background and non-uniform illuminations. (a) Original images [Caltech, on line] [Fei-Fei, 2004]. (b) Watershed pixels. (c) Backgrounds. (d) Foregrounds. (e) Extracted face.

Table 24. Performance evaluation of face extraction method for various images [Caltech, on line] [Fei-Fei, 2004].

Person id	Sample Images	No. of Successful face extraction / Total images of the person in the test set	Successful face extraction %
Person 1		17 / 21	80.9
Person 2		7 / 11	63.6
Person 3		4 / 4	100
Person 4		11 / 14	78.5
Person 5		14 / 16	87.5
Person 6		5 / 7	71.4
Person 7		11 / 13	84.6
Person 8		4 / 4	100
Person 9		4 / 4	100
Person 10		3 / 5	60
Person 11		4 / 4	100
Person 12		5 / 6	83.3
Person 13		4 / 4	100
Other		2 / 2	100
Total		95 / 115	82.6

6.11.2 Similar Face Image Retrieval

The method described in Algorithm 7, Section 6.8 is applied on precisely extracted face region for comparison of shape correlation coefficients to retrieve similar face images.

6.11.2.1 Performance Evaluation

The performance measure Precision & Recall have been tabulated in Table 25 for 5 sample images of Caltech database.

Table 25. Precision, Recall & F – measure at different similarity cut-offs. Similar face-image retrieval.

Query Images Caltech [Caltech, on line] [Fei-Fei, 2004]	Similarity cut-off	Retrieved relevant images - rr	total retrieved images - total	Total relevant images in the database - Total	Recall r = rr / Total	Precision p = rr / total	F - measure
Image_0001.jpg 	50	17	60	21	0.81	0.28	0.42
	60	15	25		0.71	0.6	0.65
	70	6	8		0.29	0.75	0.42
	80	2	2		0.10	1	0.18
Image_0007.jpg 	50	18	71	21	0.86	0.25	0.39
	60	16	54		0.76	0.30	0.43
	70	10	24		0.48	0.42	0.45
	80	7	7		0.33	1	0.50
Image_0047.jpg 	50	8	59	14	0.57	0.14	0.22
	60	8	45		0.57	0.18	0.27
	70	7	19		0.5	0.37	0.43
	80	3	3		0.21	1	0.35
Image_0079.jpg 	50	5	21	16	0.31	0.24	0.27
	60	5	6		0.31	0.83	0.45
	70	5	5		0.31	1	0.47
	80	4	4		0.25	1	0.40
Image_0122.jpg 	60	4	25	13	0.31	0.16	0.21
	70	3	4		0.23	0.75	0.35
	80	1	1		0.08	1	0.15

The average Precision and average Recall at different similarity cut-offs have been shown in Table 26. The corresponding P – R curves are plotted in Figure 100.

Table 26. Average Recall, average Precision & average F – measure at different similarity cut-off. (Similar face image retrieval).

Similarity cut-off	Average Recall	Average Precision	Average F-measure
50	0.51	0.23	0.32
60	0.44	0.6	0.51
70	0.36	0.75	0.49
80	0.19	1	0.32

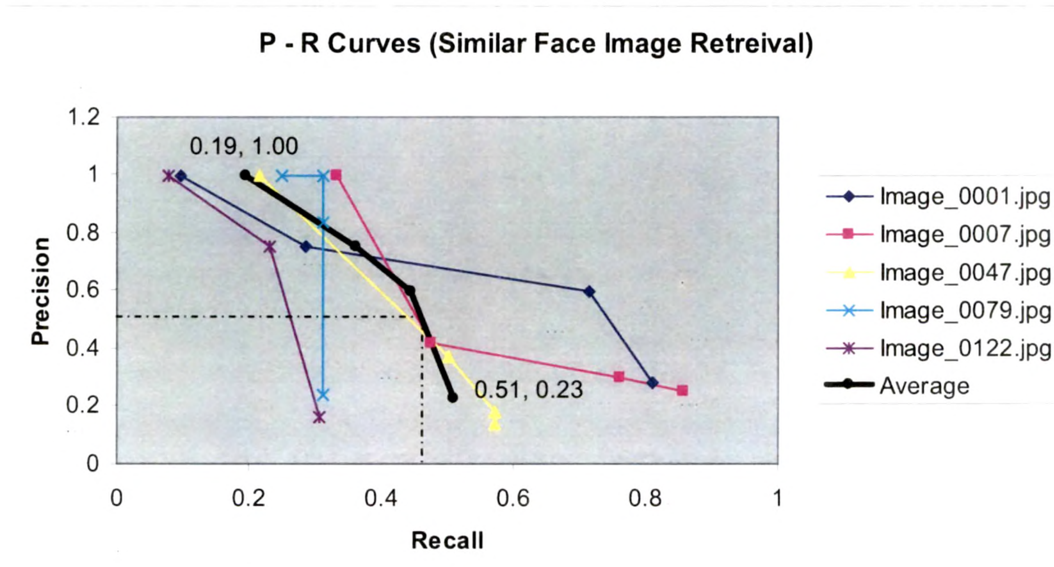


Figure 100. P – R curves. Similar face image retrieval.

Following points are observed:

- The nature of obtained P – R curves matches with the practical P – R curves.
- Stricter similarity cut-off increases the Precision at the cost of Recall.
- Despite vast variations in foreground / background colors, poses and illumination conditions, good Recall with good Precision is achievable for many sample queries.
- For all queries, Precision of 1.0 is achieved at higher cut-off.
- Range of average performance measures for all queries
  - 100 % of average Precision for 19 % of average Recall
  - 23 % of average Precision for 51 % of average Recall
  - Giving 77 % of fall in average Precision to raise average Recall by 32 %
- Lower similarity cut-offs – less than 60, are not recommended for good performance.

- The exponentially extended trend line intersects average Precision = (0.5) line at average Recall at value 0.45 (approx.) implies good performance measures for images of the class.

6.11.2.2 Query Response Example

The query response for retrieving similar-face images with 70 as similarity cut-off is shown in Figure 101. The illustrated response signifies Precision of 75% for 28% of Recall for images having complex backgrounds and face-regions constituting a small portion of images in a database of 115 images.

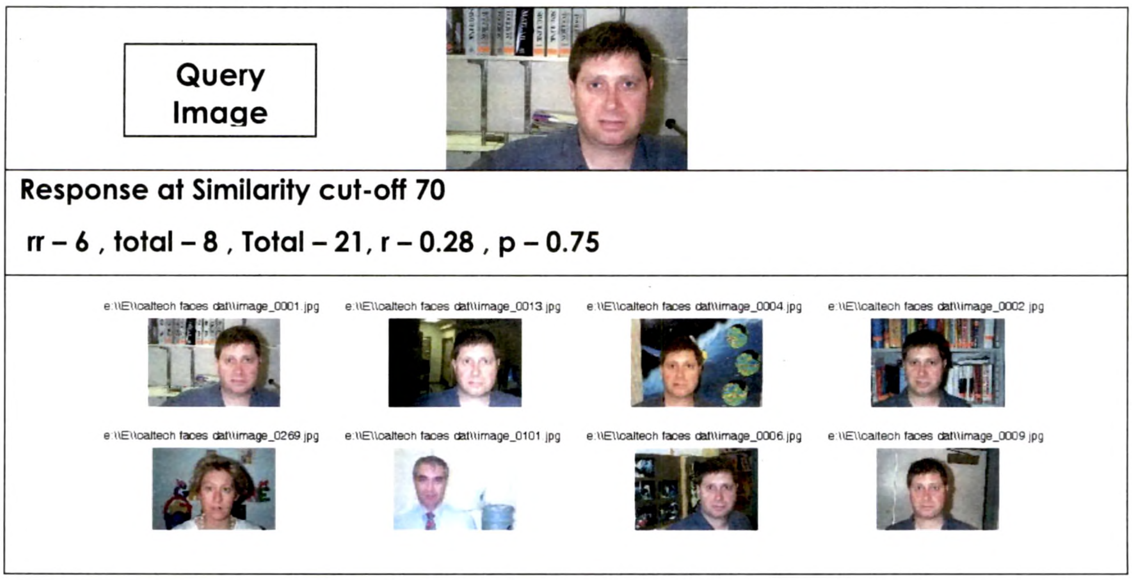


Figure 101. Query Response – similar face-image retrieval.

6.11.2.3 Discussion

- The effectiveness of methods for prominent boundaries detection & foreground separation for precisely extracting face by excluding complex background has been utilized for obtaining face-features and similar-face images. The method incorporates only face shape-feature for similarity comparison.
- Inclusion of other face-features for similarity comparison will improve the performance of the system.

6.12 Performance Comparisons with other CBIR Techniques

The relative performance comparisons of proposed methods with the state of the art CBIR techniques is not feasible because (i) unavailability and un-disclosure of comprehensive technical details of state-of-the-art techniques which are commercial, proprietary or patented. (ii) Available on-line demos of some of the CBIR systems neither reveal the details of the image database needed for Precision & Recall computations nor permit our exclusive image database to be uploaded for testing and P – R computations.

The performance of proposed CBIR algorithms can be compared and shown superior to CBIR system covered in Chapter 2 having similar test conditions. As mentioned on Page No 27, various CBIR techniques have been proposed in [Kekre, 2010, 1] & [Kekre, 2010, 2] for different classes of SIMPLIcity image database [Wang, 2001] [SIMPLIcity, on line]. The maximum Recall obtained in all seven methods proposed is about 0.35 (quite low) for 100 retrieved images (relevant + irrelevant) in [Kekre, 2010, 1] & [Kekre, 2010, 2]. And, even for retrieving 2 images, the Precision is less than 0.2 (very low) and drops further sharply with increase in no of retrieved images. *The performance measures for image retrieval with proposed techniques presented in the Chapter are significantly better compared to those of [Kekre, 2010, 1] & [Kekre, 2010, 2].*

As mentioned on Page No 26 & 27, Paitakes et al. [Pratikakis, 2006] proposed a novel unsupervised method for image retrieval based on hierarchical watershed algorithm and presented P - R curves. The mean precision-recall have been measured in [Pratikakis, 2006] for 10 queries per image-class of image database consisting of total 1000 images of 10 different classes with 100 images per class, reading (approximate values) for all categories of images, highest mean Precision of 0.7 at mean Recall of 0.07 and highest mean Recall of 0.425 with mean Precision of 0.41. Further, P – R curves corresponding to all image categories indicate that it is not possible to retrieve images with precision as 1 at any cost of recall, i.e. for no case, only relevant images get retrieved. *The performance measures with proposed techniques of image retrieval are far better than given in [Pratikakis, 2006].*

The foreground extraction and similar face image retrieval applied on un-cropped images of Caltech [Caltech, on line] [Fei-Fei, 2004] has not been known reported in the literature.

The ideal P – R curve is characterized by highest and constant Precision value 1 for all Recalls, as shown in Figure 11 on Page 43. But, as described in Section 3.3.3, the practical P – R curves are characterized by fall in Precision for increase in the Recall. Improvement in one measure compromises the other for any Practical CBIR system. In other words, P – R curves of a practical CBIR system indicates how Precision degrades with increase in Recall. Hence, a CBIR system giving high Precision with high Recall is considered to be a good system in terms of the P – R performance measures.

The exhaustive CBIR results, analysis and inferences of these performance measures for quantitative analysis of proposed methods based on (i) Color codes of entire image (ii) Foreground color codes (iii) Foreground shape correlation (iv) Combination of foreground color codes and shape correlation with selectable percentage proportion of weight of foreground color codes and foreground shape correlation for composite similarity measure (v) Similar face – images containing complex background have been carried out in various sections of the Chapter. The performance of the proposed methods can be judged with following absolute P – R measures:

- The fall in Precision is low for increase in Recall
- The average Precision at 0.5 giving good Recall
- Precision of 1 is attainable for some methods with some queries

The option of selecting the method of image retrieval with broader color descriptors, foreground shape and foreground color descriptor with selectable weights, maps the need and perception of a user giving good absolute performance measures of Precision & Recall.

6.13 Concluding Remark

A user has been offered to opt for the method of retrieval to map needs & choice for Retrieval with good Precision & Recall …