Defence Science Journal, Vol. 52, No. 3, July 2002, pp. 285–291


# Content-based Image Retrieval by Spatial Similarity

Archana M. Kulkarni and R.C. Joshi

*Indian Institute of Technology, Roorkee* – 247 667

**ABSTRACT**

Similarity-based retrieval of images is an important task in image databases. Most of the user's queries are on retrieving those database images that are spatially similar to a query image. In defence strategies, one wants to know a number of armoured vehicles, such as battle tanks, portable missile launching vehicles, etc. moving towards it, so that one can decide counter strategy. Content-based spatial similarity retrieval of images can be used to locate spatial relationship of various objects in a specific area from the aerial photographs and to retrieve images similar to the query image from image database. A content-based image retrieval system that efficiently and effectively retrieves information from a defence image database along with the architecture for retrieving images by spatial similarity is presented. A robust algorithm $SIM_{def}$ for retrieval by spatial similarity is proposed that utilises both directional and topological relations for computing similarity between images, retrieves similar images and recognises images even after they undergo modelling transformations (translation, scale and rotation). A case study for some of the common objects, used in defence applications using $SIM_{def}$ algorithm, has been done.

**Keywords:** Content-based image retrieval system, CBIR system, spatial similarity, image database system, retrieval by spatial similarity, RSS, retrieval, similarity algorithm, aerial photographs, RSS algorithm

## 1. INTRODUCTION

Recently, there has been widespread interest in multimedia technology. As such, image database system has been the subject of extensive research during the last decade of the past century and going to become one of the topics of prime importance in this century. Images are being generated at an ever increasing rate by sources, such as defence and civilian satellites, biomedical imaging, fingerprinting and scientific experiments. For example, NASA's earth observing system will generate 1 Terabyte of satellite data per day in full operation. With increase in number of applications of images, one is confronted with a greater need to manage such a large number of images efficiently. Due to difficulty in capturing the content of images using textual annotations, a content-based image retrieval (CBIR) system, which can efficiently and effectively use the information from these repositories is required. The application areas in which CBIR is a principal activity include: (i) defence applications, (ii) remote sensing and management of earth resources, (iii) geographical information system, (iv) art galleries, (v) medical imaging, (vi) interior design, (vii) weather forecasting, (viii) fabric and fashion designing, and (ix) digital libraries. A current trend in image retrieval is towards content-based retrieval. Rather than proceeding via a manually generated text-based description, CBIR works by matching the query against a (semi) automatically generated representation of the content of an image[1]. The retrieval engine returns a set of image matches that have close similarity.

Received 28 December 2001

Content-based retrieval of an image is based on the features of the corresponding image. Image has two kinds of features, visual features (colour, texture, and shape), and relationship features[2] (spatial relations among the objects in a picture). These features are extracted once in the indexing process (semi) automatically when the images are entered into the database. A few commercial content-based image retrieval systems, such as the QBIC[3] system and MIT's Photobook[4], retrieve images based on primitive features (colour, shape, and texture).

A similarity algorithm ranks images in the database according to their degree of resemblance to the query image. Similarity retrieval may use colour, shape, texture, semantic constraints and spatial constraints. Spatial relationships are important ingredients for expressing constraints in retrieval system for image databases[5]. This paper highlights a spatial approach to CBIR. Retrieval by spatial similarity (RSS) deals with a class of queries that depend on spatial relationships among domain objects[6]. An RSS algorithm ranks images in database as per similarity with the query image by applying the spatial similarity function.

By applying CBIR in defence, it is essential to know the number of defence vehicles and their spatial locations in aerial photographs. A possible query for defence image database can be to retrieve all images similar to a given query image, consisting of various objects of interest. The image retrieval system uses spatial relation of objects in an image, and a unified approach is proposed for representation of spatial relationship that integrates both directional and topological relations.

## 2. IMAGE RETRIEVAL–RELATED WORKS

### 2.1 Image Retrieval using Spatial Relationships

Chang[7], *et al.* have proposed an algorithm for image retrieval using spatial relationships. In this, the images in the database are represented as symbolic images. Symbolic projection method based on a 2-D image representation, called the 2-D string, has been presented. This representation preserves the object's spatial knowledge embedded in the image. The spatial similarity problem then becomes a problem of 2-D subsequence matching.

### 2.2 Algorithm for Similarity Retrieval

An algorithm for similarity retrieval, based on 2-D string was proposed by Chang and Lee[8]. The symbolic image is represented as a set of triplets $(O_i, O_j, r_{ij})$ where $O_i$ and $O_j$ are the two symbolic objects and $r_{ij}$ is the spatial relationship between $O_i$ and $O_j$. All spatial relationships are stored in a hash table. A hash function is used to map ordered triples into indexes in the picture table. By searching the pre-constructed hash table for all triplets associated with a query, images matching with the query can be determined. This retrieval is based on perfect match of spatial relationship, which is a severe limitation. In general, all methods based on 2-D string can recognise translation and scaling image variants but not rotation variants.

### 2.3 Image Representation – ΘR-String

A geometry-based image representation, the ΘR-String was proposed by Gudivada[5]. This method uses the inherent geometric features in the image for image representation. Each image is represented by a set of objects having an *id*, centroid, left and right neighbours, left and right distances, which are ordered by an angle between the edge joining their centroid with the image centre-of-mass and the x-axis. The proposed spatial similarity algorithm recognises translation, scaling, rotation and arbitrary image variants.

### 2.4 Algorithm based on Spatial Orientation Graph

A spatial similarity algorithm based on spatial orientation graph (SOG) is introduced by Gudivada and Raghavan[6]. The SOG is used to represent domain objects and their spatial relationships in an image. Spatial similarity algorithm $SIM_R$ can deal with translation, scaling and perfect and multiple-rotation image variants. None of the above algorithms uses topological constraints to access similarity. The spatial similarity algorithm proposed in this study deals with both the directional and the topological constraints.

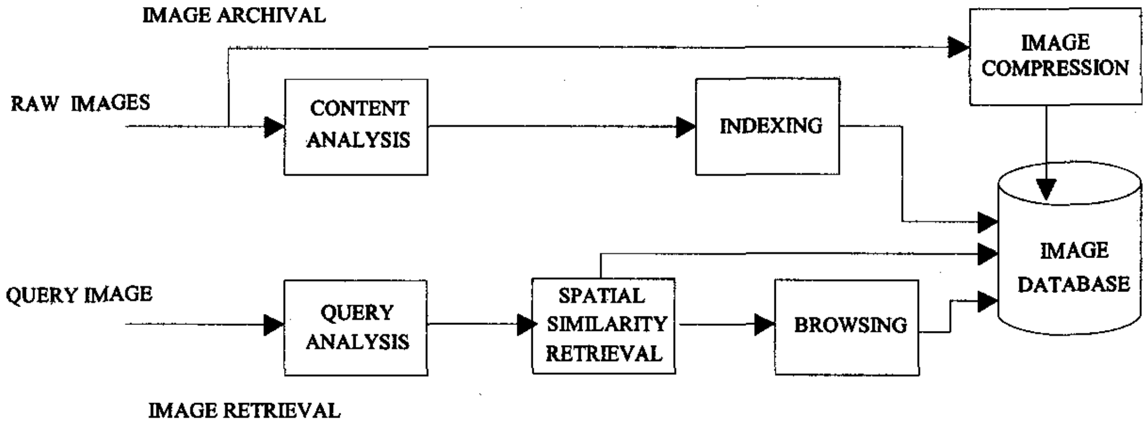



**Figure 1. Proposed architecture of image archival and retrieval**

## 3. IMAGE RETRIEVAL BY SPATIAL SIMILARITY

The proposed CBIR architecture consisting of image archival and retrieval parts is shown in Fig. 1. The system is designed to retrieve images based on spatial similarity. The system analyses contents of image, generates appropriate representation and then archives it in the image database after compression. Then, an index is assigned to information item by the indexing module. For example, an image will be represented by properties of the image objects and their spatial relationships. The image database is a repository of the derived information as well as the images in raw form. In the image retrieval process, the query analysis module first analyses the query and generates content description. All the stored contents are ranked as per the similarities between their indices and the query description by the retrieval module. A ranked list is passed to the browsing module and the user can browse and explore the contents.

### 3.1 Image Content Analysis

Spatial relations may be classified into directional and topological relations. The frequently used directional relations are north, south, east and west. Some researchers add the mixed directional relations like northeast, northwest, southeast and southwest; others use the positional directional relations like left, right, above and below[10]. These relations are shown in Fig. 2(a). There are eight fundamental topological relations between the two planar regions, such as disjoint, meets, contains inside, overlap, covers covered by, and equals[11]. These are shown in Fig. 2(b). Directional relations are not sufficient for characterising spatial similarity because they only consider the spatial orientation of an object while ignoring its spatial extent. In addition, directional relations are not rotation-invariant. Topological relations, on the other hand, always exist between any two objects and are mutually exclusive. Topological relations are preserved under perfect translation, scaling or rotation transformation.

Various forms exist for image representation in image databases. For an image representing information at the pixel level called the physical image, various image processing and image understanding techniques are used to identify the objects in the image and their relative positions

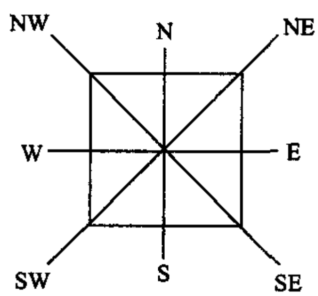



**Figure 2(a). Directional relations**

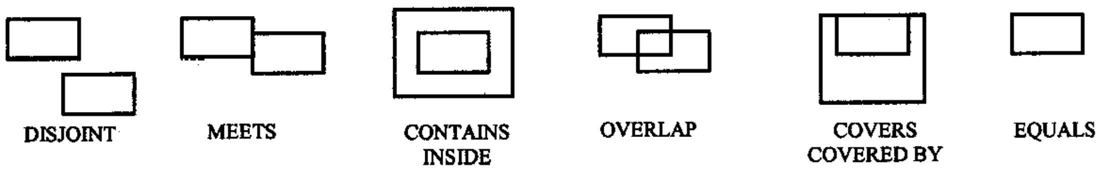



**Figure 2(b). Topological relations**

within the image. For example, image colour histogram is an appropriate logical feature to process colour similarity queries. For spatial similarity queries, various logical representations exist, such as 2-D string[7], spatial orientation graphs[6] (SOGs) and the symbolic image[9].

The symbolic image used here is a logical representation of the physical image. Image segmentation and image understanding techniques are used to identify the objects in the image and their relative positions within the image. Since the logical images require negligible space relative to physical images, the logical images are useful in distributed environment. The physical images are stored only at a central node, whereas the logical images are stored at each local node. Only those images relevant to a query need to be transferred from the central node to the local node[6]. The image objects are represented in the form of a centroid or the corners of minimum bounding rectangles (MBRs). The MBR is the minimum size rectangle that completely encloses a given object.

### 3.2 Image Indexing

Indexing images by their object contents is crucial to effective search and retrieval in an image database. The collection of image objects in image databases can be quite large. Efficient indices are required to accelerate the searching process. There are many methods for indexing in multi-dimensional space[12,13]. The proposed CBIR system provides a sophisticated indexing technique for content-based image indexing using multi-dimensional B+ trees[14]. Multidimensional B+ tree exploits the major features of the B+ tree and establishes an index structure in multidimensional space based on a linear order. This linear order gives the multi-dimensional B+ tree various advantages overR-tree[12] and its variants[13], such as the space required for each entry at the leaf level is reduced by nearly half, the insertion and deletion operations are simpler, giving better performance in searching.

### 3.3 Retrieval by Spatial Similarity

The spatial similarity retrieval deals with a class of queries based on spatial relationships among the domain objects. A new similarity algorithm $SIM_{def}$ for similarity by directional and topological relations is introduced. The algorithm assesses similarity between the two images based on the number of common objects between the two images and the directional and topological relations between the objects.

In the similarity algorithm, directional spatial relationships between objects in symbolic image are represented as edges in a SOG[6]. An edge list corresponding to each symbolic image and query image is then constructed. An edge is a line connecting the centroids of two objects and the weight associated with the edge is the slope of that edge.

The similarity function uses the edge list of query image ($E_{qr}$) and that of the database image ($E_{db}$) to compute the degree of closeness between the two images. The directional similarity function $SIM_{def}$ is a function defined as $SIM_d$: $\{(E_{qr}, E_{db})\}|(0,1)$.

The function used to estimate topological similarity between the two objects $O_i$ and $O_j$ is called $t(O_{ijq}, O_{ijd})$ and it returns 1 if the same topological relation holds in $I_q$ and $I_d$ between the objects $O_i$ and $O_j$, and 0 otherwise. The $SIM_{def}$ algorithm is shown in Fig. 3.

| | |
|---|---|
| *Input* | $I_{qr}$ is a query image and $I_{db}$ is a database image |
| *Output* | Spatial similarity between $I_{qr}$ and $I_{db}$ |
| Let | |
| $N_{qr}$, $N_{db}$ | Number of objects in query, database image |
| $E_{qr}$, $E_{db}$ | Edge list of the query, database image |
| $c$ | Number of common objects between $I_{qr}$ and $I_{db}$. |

The procedure is to be followed as

- Find common objects in $I_{qr}$ and $I_{db}$
- Compute directional spatial similarity $SIM_d$
- Compute topological spatial similarity $SIM_t$
- Compute spatial similarity $SIM_{def}$

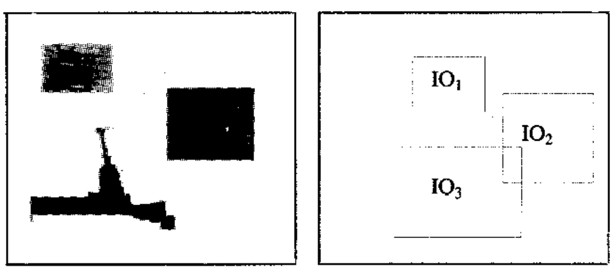
$$SIM_{def} = \frac{c}{N_{qr}} + \frac{1}{N_{qr}(N_{qr}-1)/2}(SIM_d + SIM_t)$$

**Figure 3. $SIM_{def}$ algorithm**

The time complexity of $SIM_{def}$ is $O(|E_{qr}|+|E_{db}|)$ since the algorithm involves searching for each edge in $E_{qr}$ for corresponding edge in the sorted list of $E_{db}$.

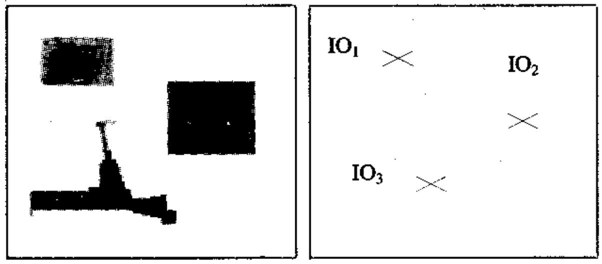
## 4. RESULTS

The image used for testing the results of $SIM_{def}$ algorithm is shown in Fig. 4(a). It has three defence objects–tank, truck, and Bofors gun. These objects are given *ids* $IO_1$, $IO_2$ and $IO_3$, respectively. Fig. 4(b) shows the objects extracted from the image and their corresponding MBRs. Example




(a) (b)

**Figure 4. $SIM_{def}$ algorithm: (a) original image and extracted objects and (b) MBRs and object *ids*.**

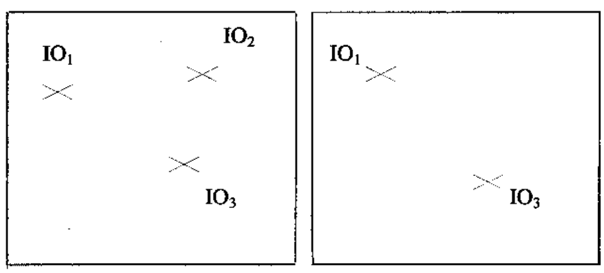



(a) (b)

**Figure 5. $SIM_{def}$ algorithm: (a) example image and (b) logical representation.**

image and its logical image representation in which each object is represented by its centre of mass is shown in Fig. 5. Now consider the query image in Fig. 6(a), which shows the logical image representation of original image after rotating all objects by 45° about the image centre of mass.

To calculate similarity between this image and the original image, angle is calculated to be −45°. Rotating all the objects by this angle will align query image with the original image, and $SIM_{def}$ will compute the closest similarity value of 1. Figure 6(b) shows another query consisting of only two objects. The spatial similarity algorithm will compute similarity between the query image and the database image. The proposed CBIR system will give all images having common objects to the query image. As it is very difficult to get real defence aerial images, experiments were conducted to test the algorithm using a collection of created synthetic test images. However, the algorithm can easily be extended for real-life images using a good segmentation algorithm. The performance of the algorithm was tested on the synthetic images and it was observed that the algorithm performance is good up to 5000 images.




(a) (b)

**Figure 6. $SIM_{def}$ algorithm: (a) all objects rotated by 45° about the image centroid (query 1) and (b) image consists of only two objects (query 2).**

The processing time of the similarity algorithm was measured. The tests were carried out on a PC with a pentium III processor (866 MHz) and 128 Mbyte RAM. For every query, the database image matching takes about 4 s to 10 s.

## 5. CONCLUSION & FUTURE SCOPE

This paper introduces a general architecture of CBIR system for defence applications. An efficient algorithm for retrieving images by spatial similarity in image database has been presented. The proposed algorithm deals with both the directional and the topological spatial relations and it is translation, scaling and rotation-invariant. Experiments to test the algorithm used created gray scale symbolic images of various objects used in defence applications.

To avoid exhaustive search in defence image database, currently the multidimensional $B^+$ trees for indexing are being used. The results are encouraging. Future research directions include incorporating the more sophisticated indexing mechanism to $SIM_{def}$ algorithm, and use of skeletons for object representation. Further efforts will extend the present work to real image repositories and video retrieval.

## REFERENCES

1. Gudivada, V.N. & Raghvan, V.V. Content-based image retrieval systems. *IEEE Computer*, 1995, **28**(9), 18–22.

2. Smith, J. & Chang, S. VisualSeek: A fully automated content-based image query system. *In* Proceedings of the ACM Multimedia 96. ACM Press, New York, 1996. pp. 87–98.

3. Niblack, W.; Barber, R.; Equitz. W.; Flickner, M.; Glasman, E.; Petkovik, D.; Yanker, P.; Faloutsos, C. & Taubin, G. The QBIC project: Querying images by content using colour, texture, and shape. *In* Proceedings of SPIE–Storage and retrieval for image and video databases, 1993. pp. 173–87.

4. Pentland, A.; Picard, W. & Sclaroff, S. Photobook: Tools for content-based manipulation of image databases. *In* Proceedings of SPIE–storage and retrieval of image and video databases–II, **2185**, 6–10 February, 1994, San Jose, CA. pp. 34–47.

5. Gudivada, V. N. ΘR-String : A geometry-based representation for efficient and effective retrieval of images by spatial similarity. *IEEE Trans. Knowledge Data Engg.*, 1998, **10**(3), 504-12.

6. Gudivada, V. N. & Raghvan, V. V. Design and evaluation of algorithms for image retrieval by spatial similarity. *ACM Trans. Inf. Syst.*, 1995, **13**(2), 115–44.

7. Chang, S.K.; Shi, Qing-Yun & Yan, Cheng-Wen. Iconic indexing by 2-D strings. *IEEE Trans. Pattern Anal. Mach. Intell.*, 1997, **PAMI-9**(3), 413–28.

8. Chang, C. & Lee, S.Y. Retrieval of similar pictures on pictorial databases. *Pattern Recognition*, 1991, **24**(7), 675–80.

9. Gudivada, V.N. & Jung, G.S. An algorithm for content-based retrieval in image databases. *In* Proceedings of the Inter. Conf. on Multimedia Computing and Systems. Hiroshima, Japan, June 17–23, 1995. pp. 90–97.

10. Sistla, P.; Yu, C. & Haddad, R. Reasoning about spatial relationships in picture retrieval system. *In* Proceedings of the 20th VLDB Conference, Santigo, Chile, 1994. pp. 570–81.

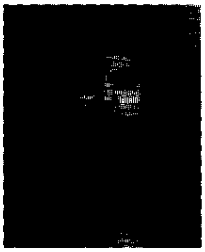
11. Papadias, D.; Theodoridis, Y.; Sellis, T. & Egenhofer, M.J. Topological relations in the world of minimum bounding rectangles: A study with R-trees. *In* Proceedings of the ACM SIGMOD International Conference on Management of Data, SIGMOD'95, San Jose, CA, May 23–25, 1995. pp. 92–103.

12. Guttman, A. R-tree: A dynamic index structure for spatial searching. *In* ACM SIGMOD, 1984. pp. 47–57.

13. Beckmann, N.; Kriegel, H.P.; Schneider, R. & Seeger, B. The R-tree: An efficient and robust access method for points and rectangles. *In* ACM SIGMOD, 1990. pp. 322–31.

14. Dao, S.; Yang, Q. & Vellaikal, A. $MB^{+}$-tree: An index structure for content-based retrieval. *In* Multimedia database systems: Design and implementation strategies, edited by C. Kingsley, Bhavani Thuraisingham and P. Bruce Berra. Kluwer Academic Publishers, 1996. pp. 298–317.

**Contributors**



**Ms Archana M Kulkarni** received her ME (Instrumentation) from the Marathwada University, Aurangabad. She joined as a faculty member in M.G.M College of Engineering, Nanded, in 1991 and served as Head, Dept of Computer Engineering, during 1997–99. Currently, she is a PhD student in the Dept of Electronics and Computer Engineering at the Indian Institute of Technology(IIT), Roorkee. Her research interests are: Multimedia and image databases, image processing and computer vision, and pattern recognition. She is a student member of the IEEE Society.

**Dr RC Joshi** received his ME and PhD from the University of Roorkee in 1970 and 1980, respectively. He served as Head, Dept of Electronics and Computer Engineering at the University of Roorkee [now IIT, Roorkee] during 1991–94 and 1997–99. He visited France under Indo-French Collaboration Programme during 1978–79. Currently, he is Professor in the Electronics and Computer Engineering Dept and Head, Computer Centre, at IIT Roorkee. He has guided more than 10 PhD students and about 100 MTech students. He was awarded Gold Medal by the Instituion of Engineers in 1978 for the best research paper. His research interests include: Parallel and distributed computing, mobile computing, computer networks, multimedia, and image databases.