Toward Content-Based Satellite Image Database Systems over the Network

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Abstract

Content-based image retrieval technology is vital for effective searching and browsing in the large archive of imagery. To realize content-based image retrieval, this paper proposes the "hierarchical model of image content elements" as the image representation model. This model consists of five layers, where each layer defines image content elements to be extracted and indexed, and similarity metric associated with them. Image database systems are then considered under network environment, and the idea of a meta search engine for distributed image database systems is proposed to improve accessibility to various contents of satellite imagery. Finally the results of content-based image retrieval demonstrate the effectiveness and potential of content-based image database systems.

1 Introduction

"Content-based image retrieval" wins high popularity recently [1, 2] because it is one of the key technology for realizing intelligent image database systems. What characterizes content-based image retrieval is the direct indexing of image contents automatically or semi-automatically extracted from the image, instead of textual information manually or semi-automatically attached to images. This way of indexing has several merits as follows. Firstly, image contents cannot be fully described by text. Although textual information or *keywords*, such as acquisition date, image name, special phenomenon, and so on, play an important role in representing image contents, other types of image contents such as color, shape, texture and structure are numerical in nature and cannot be well represented in textual form. Secondly, it is still a hard task for the current level of technology to automatically abstract high-level symbols from low-level image features. Thus, instead of trying for automatic symbol (keyword) assignment to images, it is better to consider how to make the most of information that can be extracted from the image itself by means of many pattern recognition techniques. Thirdly, manual assignment (entry) of keywords becomes prohibitive for the large archive of imagery due to cost and consistency. That is, the task of assigning keywords requires intensive human operations, and it requires the deliberate assignment of keywords based on carefully defined decision criteria to maintain consistency for the overall image archive.

Therefore, the author focuses on content-based image database systems that are based on image contents extracted from the image itself. For this purpose, the author proposes the architecture of content-based image database systems, in which the key idea lies in the representation of image contents in a hierarchical manner. That is, the proposed model [3], "hierarchical model of image content elements," represents image contents as a set of five layers covering from low-level to high-level image content elements. Each layer specifies image content elements to be extracted and indexed, and similarity metric associated with them. This framework accepts various levels of query, because similarity is calculated on the appropriate level of a given query. The author then discusses image database systems under network environment, in which the idea of a meta search engine is introduced in detail. Finally prototype image database systems for satellite imagery are presented, and experimental results demonstrate the effectiveness and potential of content-based image database systems.

Table 1: Two aspects of image contents for three important categories in satellite imagery.

	Occlusion	Material
Land	Yes	Solid
Sea	Yes	Fluid
Cloud (Atmosphere)	No	Fluid

2 Architecture of Image Database Systems

2.1 Image Contents of Satellite Imagery

Image contents in general are too complex to represent in a unified way. Even if we restrict the domain of imagery to satellite imagery, we can still think of vast amount of image contents appearing on an image. However, the basic image contents of satellite imagery can be categorized as *land, sea and cloud*, whose properties are summarized in Table 1. Firstly, the property "occlusion" refers to the restriction of observation from a satellite, namely the loss of information on land and sea when covered by cloud. Then a query like "*Is the required pixel / region is occluded by cloud?*" becomes an important query on land and sea. Secondly, the property "material" refers to the issue of shape representation. Fluid materials, which consist of sea (water) and cloud (vapor), can take unlimited variety of shape and their shape even changes with time. Then a query like "*where is a sea current or a cloud region and what kind of shape does it look like?*" becomes an important query on sea and cloud.

In this paper, the author specifically focuses on *cloud* appearing on satellite imagery. This is because cloud is the interesting subject of research for its complexity in shape, pattern, and movement. It can always be observed without occlusion in the sense stated above (especially in infrared imagery). In short, the author claims that cloud is the very challenging subject of research.

2.2 Various Query Levels

Before proceeding to the detail of the architecture of content-based image database systems, let me first summarize typical queries for satellite cloud imagery. The most basic queries may be something like this: "*Search for images in which Typhoon No. 10 appears.*" This may be a useful query for a user who wants to track the movement of Typhoon No. 10. However, this query can only be answered by searching for keywords "Typhoon No. 10" attached to images, which information cannot be extracted from the image itself, but alternatively from the external sources of information such as weather map or weather report. Hence, in spite of the usefulness of keyword-based queries, the author excludes this type of query in this paper, and focuses on what pattern recognition techniques can contribute to content-based image database systems.

Another basic query based on image information may be: "*Search for images that contain many cloud pixels.*" This query can be handled by first counting the number of cloud pixels on an image, then sort all the archived images by the number of cloud pixels. This procedure shows that necessary information for this query is the "class" or "label" of each pixel. It is then natural to call this query a "pixel-level query." Now suppose a more complex query like: "*Search for images with two elongated cloud regions in parallel extending from east to west.*" This query requires the extraction of cloud regions, and spatial relationship between cloud regions, hence this type of query can be called "relation-level query." In the same manner, a query like *"Search for images that look like this image,"* requires the calculation of similarity for each archived image to the query image. Similarity metric used here should allow a user to specify his or her relevance on specific image features. In addition, this similarity metric should be associated with the image representation model used in image database systems. Therefore this high-level query can be called "semantics-level query." In summary, we should consider various query levels from simple ones to complex ones.

2.3 Hierarchical Model of Image Content Elements

The idea of various query levels leads to the concept of the "hierarchical model of image content elements" [3], where image contents are represented by a set of five layers as described in Table 2. This hierarchy corresponds to the different abstraction levels of image contents from low-level features to high-level features, namely observation layer, pixel layer, region layer, relation layer, and semantics layer. As the author will

Table 2: The hierarchical model of image content elements.

	Layer	Content Elements	Algorithm
5	Semantics Layer	Parameters representing the semantics of the image or *kansei* (subjectivity, feeling) models of users	Genetic algorithms [4]
4	Relation Layer	Content elements representing relationship between regions	Hierarchical attributed relational graph (image representation model) [5]
3	Region Layer	Content elements representing shape features or structural features of a region	Representation of complex shape by shape decomposition [6]
2	Pixel (Atom) Layer	Class or label assigned through pixel-based classification / segmentation techniques	Statistical pattern recognition technique [7, 8, 9, 10]
1	Observation Layer	Image array obtained from the observation of the real world through sensors with the application of basic image correction techniques	Satellite sensors, geometric correction

introduce later, the frequent application of such hierarchical models to many scientific domains supports their application to image database systems. In computer vision, for instance, one of the basic framework is based on the concept of layered representation, namely raw image, primal sketch, $2\frac{1}{2}$-D sketch, 3-D sketch [11]. Other example is the on-going MPEG-7 project, which aims at establishing the standard description of various types of multimedia information. Although the standard is yet to be established, the notion of various abstraction levels plays an important role here also. In comparison with these examples, the specific number or the way of division of layers in this model may be different, so the implementation of the model may be domain dependent. However, the advantage of using a hierarchical model lies in the fact that it clarifies the structure of image database systems, hence serves as a framework for implementing image database systems for various domains. Hereafter the author briefly describe each layer of the model, but the detail of algorithms and implementations used in each layer is beyond the scope of this paper.

1. Observation Layer This is a layer in which the result of observation through a sensor is recorded in the form of an image array. The image array then undergoes such methods as image reconstruction, image correction and noise reduction to maintain the required precision of observation. For satellite imagery, geometric correction and atmospheric correction are popular examples. Hence content elements to be extracted is a possibly corrected image array itself.

2. Pixel (Atom) Layer This is a layer that deals with the smallest content elements (atom) on the image array, where the smallest element is usually assumed to be an image pixel. One of the basic processes is to distinguish relevant pixels from irrelevant ones, which process is achieved by many binarization techniques. More advanced processes such as clustering and classification are also applied on the global statistics of pixel values on an image array. In these cases, content elements to be extracted is the "class" or "label" of each pixel. Other approaches are based on local statistics to detect significant changes on pixel values. In this case, the smallest content elements is an edge element or a "token."

3. Region Layer This layer defines a region, a set of connected pixels which belong to the same class, or a set of pixels enclosed by grouped edge tokens. Since a region has size, a region can be characterized by calculating many types of image features, such as area, shape features and texture features. More advanced approaches include shape decomposition based on the internal structure of a region, or polygonal approximation based on the boundary structure of a region. In short, content elements to be extracted is a region.

4. Relation Layer This layer defines relationship between regions. The most obvious relationship is adjacency, but we can also define other types of relationship. To name a few, simple relationship assigning labels such as above/below/left/right, remote action models on the analogy of physical models, or subjective relationship based on cognitive computational models. Content elements to be extracted is relationship between regions.

5. Semantics Layer The highest layer should deal with the semantics of images, or *kansei* (subjectivity, feeling) models of users. Hence this layer plays an important role for realizing flexible and intelligent image retrieval. Issues like reflecting the viewpoint of a user on a specific search, modeling the impression of a user on an image, calculating semantic similarity between image representation models, are all covered by this layer. Ideally these models should be derived from or related to the cognitive models of human beings; however practical solutions to this problem are adaptive systems that learn from human computer interaction or preselected training data.

For each image, image contents are automatically extracted by means of various image processing techniques used in each layer of the hierarchical model. Examples of image processing techniques used in this paper are also summarized in Table 2. In image retrieval stage, a query given by a user is handled on the appropriate layer of image content elements, and similarity between a given query and archived images is calculated based on the similarity metric defined on the same layer.

3 Network of Image Database Systems

3.1 Image Database Systems over the Network

Now let me move on to another important topic, namely network. In this Internet Age, we should consider image database systems in such a context that many image database systems are connected and distributed over the network. Although receiving stations of satellite imagery are distributed in the world, many of those are now connected to the Internet, and some of them opened up a service to allow access to the large archive of satellite imagery received there. To make the most of this environment, the network plays an important role in the future development of satellite image database systems.

However, as the amount of information provided on the Internet grows to overwhelmingly large volume, it turned out that it is almost impossible to reach required information without the help of Internet search engines. Moreover, as the Internet grows too rapidly, each search engine cannot construct indexing on all available information resources on the Internet; in other words, each search engine can cover only a part of the whole Internet resources. This situation leads to the idea of a "meta search engine," whose purpose is to combine and integrate search results obtained from multiple search engines.

In terms of satellite imagery, it is also natural to imagine a meta search engine for satellite imagery. Although many satellite receiving sites archive satellite imagery received at their own sites, carrying out a global search that covers satellite imagery received at multiple sites is still a difficult task, partly because the huge size of satellite imagery has prevented the intensive exchange of image collections via the network, and partly because image collections are archived and indexed in a proprietary manner without any standards. However, from the analogy of general Internet resources, a meta search engine for satellite imagery may solve a part of the problem.

3.2 Meta Search Engine for Distributed Image Database Systems

Important research issues related to a meta search engine for satellite imagery can be listed as the following.

1. Collecting "summary" data such as quicklook imagery from distributed image database systems and construct original search indices to provide users basic searching and browsing functionality.
2. Designing standard interface to be implemented at possibly proprietary distributed database systems to allow handy access from external meta search engines.
3. Collecting metadata from distributed image database systems to aid users select relevant databases and follow the links to the original location of resources.

These three issues indicate the different degree of interaction between the meta search engine and distributed image database systems.

In the first case, the meta search engine collects "summary" data such as quicklook or catalog images from distributed image database systems off-line. It does not archive original satellite images because otherwise huge computational resources are required at the meta search engine. In addition, it constructs original search

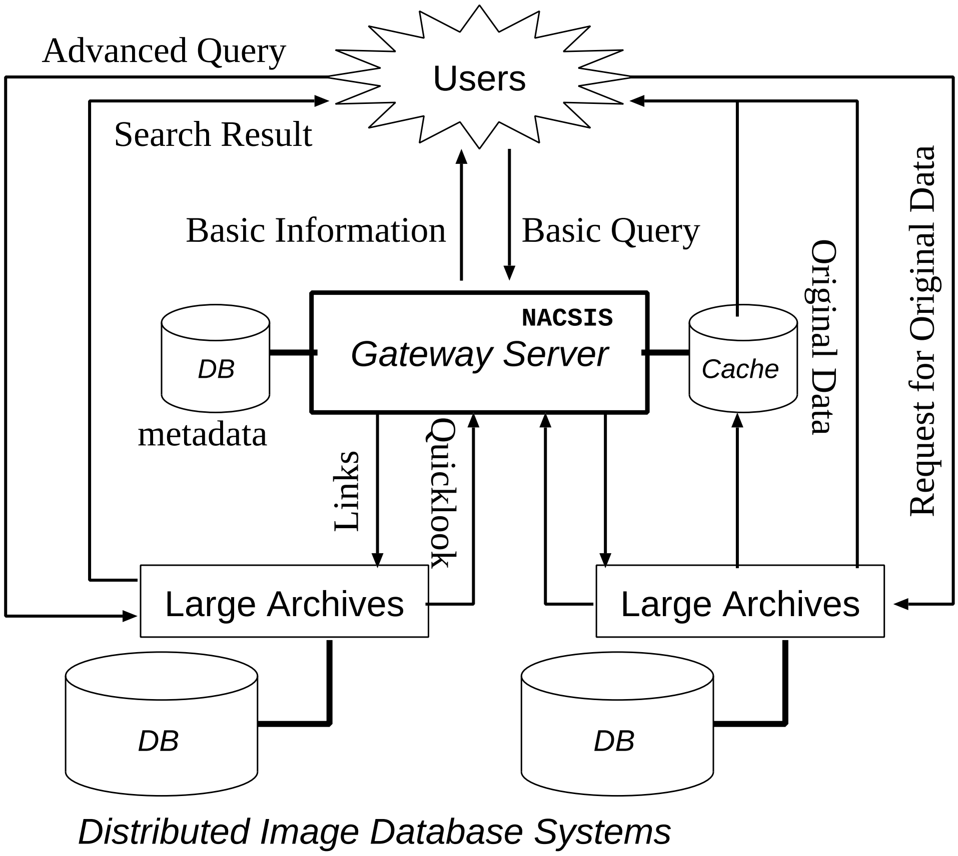


Figure 1: A gateway server and distributed image database systems.

indices from summary data, and provides basic searching and browsing functionality for satellite imagery. This is the case the author mainly focuses on in this paper.

In the second case, we need to establish the standard description framework of image contents for satellite imagery. With this standard, we can expect that search results received from multiple image database systems keep consistency over the queries submitted to distributed image database systems in accordance with the framework. Therefore we can safely collect search results from multiple image database systems and return ranked results to the user. This is the typical way of operation in meta search engines existing on the Internet. However, in general, image contents are not described in accordance with some standards, rather described in a proprietary format. Hence, without the standard, this type of meta search engine can be used only in a restricted domain, such as search for satellite images by date, area, and so on.

In the third case, the meta search engine serves as an adviser for a user to select relevant databases to the query. For example, a user may ask for the product of satellite images such as sea surface temperature and vegetation index. If those data are not available at the meta search engine, it should guide the user to submit queries to distributed image database systems where such kind of data are provided. For this purpose, the meta search engine should collect some metadata, the description and statistics of distributed image database systems, instead of information on individual images archived therein. In addition, the meta search engine should be equipped with some mechanisms to select relevant databases from the list of candidate databases.

In summary, the meta search engine serves as a starting point for searching satellite imagery in terms of various types of image contents with links to the original location of satellite imagery. In this sense, we call this server as a "gateway server" to distributed image database systems. So to speak, the "symbiosis" of the gateway server and existing distributed image database systems is important, not the "parasitism" of the gateway server to existing distributed image database systems.

3.3 NOAA Image Archives over the Network

Specifically, this paper deals with image database systems for NOAA satellite imagery. The schematic diagram of the whole system is illustrated in Fig. 1. In terms of receiving stations of NOAA satellite data, there are several both in Japan and Thailand. One of which is built at ACRoRS (Asian Center for Research on Remote Sensing), AIT (Asian Institute of Technology), where the NOAA receiving station kept its regular operation for more than one year. To handle high demands on NOAA data received at ACRoRS from many researchers who requires these satellite data, the improvement of accessibility to satellite imagery via network is an important research issue to realize near real time environmental monitoring.

In terms of bandwidth, NACSIS provides 2 Mbps link between Thailand and Japan which should be utilized as a very important infrastructure for the exchange of satellite imagery. In addition, SINET (Science Information Network) is also provided as the infrastructure of high-speed academic network inside Japan. To help the smooth transfer of satellite data from Thailand to academic institutions inside Japan, the author has an idea of setting up a cache server which temporarily archives satellite data that are on their way to the final destination.

This cache server will become a part of what the author is planning to set up at NACSIS as an experimental gateway server. To improve accessibility to satellite imagery, this server should provide content-based image retrieval functionality that cover a wide range of image contents with various types of search mechanisms, and the general applicability of the hierarchical model proposed before should be fully exploited to realize this goal. This gateway server does not archive original satellite imagery; instead it collects quicklook images constantly exchanged with multiple distributed image database systems. After the collection of quicklook images, it extracts image contents by means of pattern recognition techniques, and provides, in some sense, perspective search functionality desirable as a starting point for users to search satellite imagery and follow links to the original location of many types of available resources on the Internet.

4 Systems and Experiments

4.1 The Overview of Prototype Image Database Systems

The description of prototype image database systems now available is summarized in Table 3. Images to be searched are either NOAA or GMS. In the preprocessing stage, image content elements shown in Table 2 are extracted from all archived images, then content elements are indexed to set up prototype image database systems. In the retrieval stage, a user first gives a query to the system, where only a query in the form of an image (example image) is allowed at this time of development. Then the system searches for indices that best satisfy the query, or are most similar to the query based on specified similarity metric. Currently this similarity metric is only defined on the semantics layer, but implementation of similarity metric on other layers should be at least easier than that done on the semantics layer. Automatic selection of appropriate layer for various levels of query is remained as the future development.

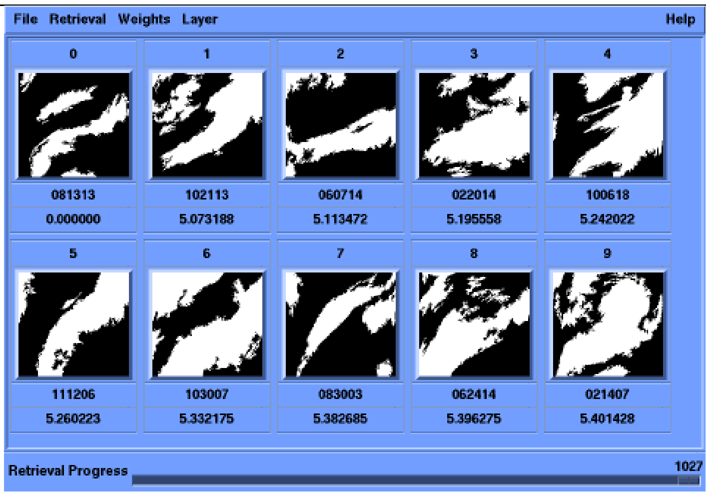
4.2 Experimental Results

Fig. 2 illustrates the description and the results of image retrieval for each prototype image database system. The image shown in the upper-left corner is the query (example image), and other images are the most similar images sorted by similarity to the query. Apparently the result of GMS infrared images (Case 2) looks like the best result compared to the other two. This is because this image database system archives satellite images taken every one hour; so it certainly contains several images that just underwent "graceful" deformation from the query image. In other words, this is the "easiest" case among three cases. In comparison, retrieval results for other cases are not clear as in Case 2. However, for each case, we can notice similarity between the query and retrieved images. For instance, in Case 3, there appear several images which can be described as "a typhoon is in the south of Japan, and an elongated cloud region is in the north of Japan." This shows that such relationship between multiple cloud regions has been represented in indices (image content elements) and influenced the calculation of similarity. As these results illustrate, because of the usage of graph structure as the image representation model, this image database system is successful in representing the spatial relationship or structural image features in addition to regional image features such as shape and color. In conclusion, experimental results demonstrated the effectiveness and potential of similarity-based image retrieval, or more broadly content-based image database systems.

Table 3: Contents of three types of prototype image database systems.

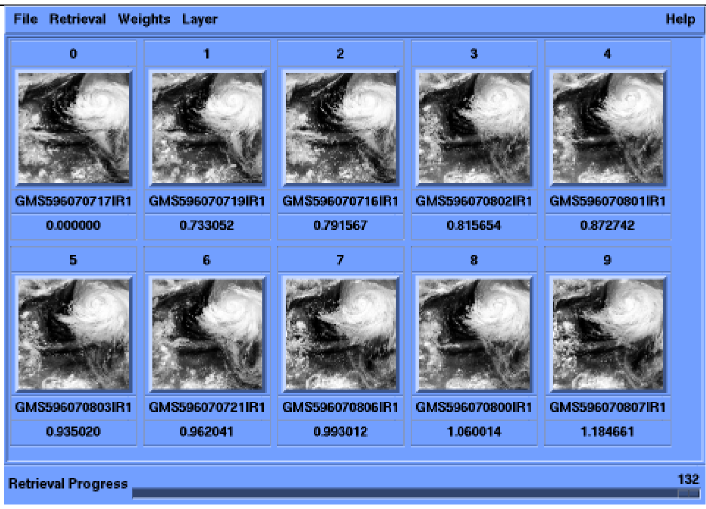
	Contents	Place	Images
1	NOAA quicklook cloud image (binary)	around Japan	1027
2	GMS infrared image (gray)	pacific ocean	132
3	GMS visible image (gray)	around Japan	331

1



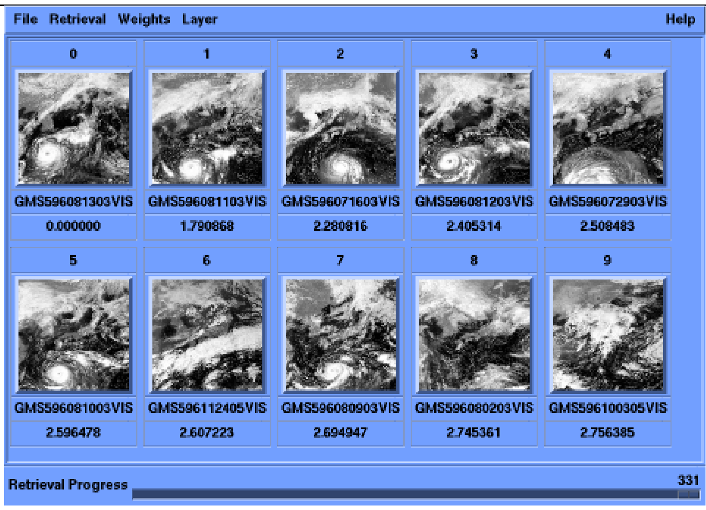
Retrieval results for NOAA quicklook cloud images (binary). These images are taken from Jun. 1991 to Feb. 1992 and the collection contains 1027 images. A set of weighting factors of similarity metric used in this retrieval puts relatively large weight on the orientation of cloud regions.

2



Retrieval results for GMS infrared images (gray). These images are taken on Jul 1996, and the collection contains 132 images. The images are taken every one hour for tracking the movement of a typhoon. A set of weighting factors of similarity metric used in this retrieval puts relatively large weight on the spatial position and the orientation of cloud regions.

3



Retrieval results for GMS visible images (gray). These images are taken from Jan. 1996 to Nov. 1996 and the collection contains 331 images. All images are taken on 12:00 noon JST, because for visible images this is the best time of observation in a day. A set of weighting factors of similarity metric used in this retrieval puts relatively large weight on the spatial position of cloud regions.

Figure 2: Retrieval results for three types of prototype image database systems.

5 Conclusion

Content-based image retrieval technology is vital for effective searching and browsing in the large archive of imagery. To realize content-based image retrieval, this paper proposed the "hierarchical model of image content elements" as the image representation model. This model consists of five layers, where each layer defines image content elements to be extracted and indexed, and similarity metric associated with them. Image database systems were then considered under network environment, and the idea of a meta search engine for distributed image database systems was proposed to improve accessibility to various contents of satellite imagery. Finally the results of content-based image retrieval demonstrated the effectiveness and potential of content-based image database systems.

There are still much work to be done. Since rich contents of satellite imagery makes it difficult to make indices on *all* image contents appearing on an image, the author restricted the range of image contents into satellite cloud imagery. However, to fulfill high demands from researchers on land and sea for content-based image retrieval systems, the extension of the proposed framework to other domains (land / sea) is the important direction of future research. On the other hand, the extension of content-based image database systems under network environment is just briefly discussed in this paper. Since NACSIS provides network resources effective for the distribution of satellite imagery, the construction of image database systems that highly exploits network environment becomes an important research issue in the future development.

References

[1] Gupta, A., Santini, S., and Jain, R. In Search of Information in Visual Media. *Communications of the ACM*, Vol. 40, No. 12, pp. 35–42, 1997.

[2] Flickner, M., Sawhney, H., Niblack, W., Ashley, J., Huang, Q., Dom, B., Gorkani, M., Hafner, J., Lee, D., Petkovic, D., Steele, D., and Yanker, P. Query by Image and Video Content: The QBIC System. *Computer*, Vol. 28, No. 9, pp. 23–32, 1995.

[3] Kitamoto, A. and Takagi, M. Hierarchical Model as a Framework for Constructing Similarity-Based Image Retrieval Systems. *Technical Report of the Institute of Electronics, Information and Communication Engineers*, Vol. PRMU97-58, pp. 25–32, 1997. (in Japanese).

[4] Kitamoto, A. and Takagi, M. Interactive Image Browsing Using Queue-Based Genetic Algorithm. *The Journal of the Japanese Society of Artificial Intelligence*, Vol. 13, No. 5, pp. 728–738, 1998. (in Japanese).

[5] Kitamoto, A. and Takagi, M. Fast Matching of Hierarchical Attributed Relational Graphs for an Application to Similarity-Based Image Retrieval. In *Meeting on Image Recognition and Understanding (MIRU'96)*, Vol. II, pp. 331–336, 1996. (in Japanese).

[6] Kitamoto, A. and Takagi, M. Retrieval of Satellite Cloud Imagery Based on Subjective Similarity. In *The 9th Scandinavian Conference on Image Analysis*, pp. 449–456, Uppsala, 1995.

[7] Kitamoto, A. and Takagi, M. Estimating the Area Proportions of Mixels Using Mixture Density Estimation with Mixel Densities. *The Transactions of the Institute of Electronics, Information, and Communication Engineers*, Vol. J81-D-II, No. 6, pp. 1160–1172, 1998. (in Japanese).

[8] Kitamoto, A. and Takagi, M. Image Classification Method Using Area Proportion Density that Reflects the Internal Structure of Mixels. *The Transactions of the Institute of Electronics, Information, and Communication Engineers*, Vol. J81-D-II, No. 11, pp. 2582–2597, 1998. (in Japanese).

[9] Kitamoto, A. and Takagi, M. Image Classification Using a Stochastic Model that Reflects the Internal Structure of Mixels. In Amin, A., Dori, D., Pudil, P., and Freeman, H., editors, *Advances in Pattern Recognition*, Vol. 1451 of *Lecture Notes in Computer Science*, pp. 630–639. Springer, 1998.

[10] Kitamoto, A. and Takagi, M. Image Classification Using Probabilistic Models that Reflect the Internal Structure of Mixels. *Patttern Analysis and Applications*, 1999. Accepted for Publication.

[11] Marr, D. Vision. W.H. Freeman, 1982.