Middle States Geographer, 2003, 36:113-121

USE OF TEXTURE FOR THE RETRIEVAL OF INDUSTRIAL COMPLEXES IN A DIGITAL IMAGE DATABASE

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ABSTRACT: *Image retrieval systems have been developed in an attempt to increase the utility of digital image databases. Some image retrieval systems rely on characterizing the texture of a digital image. Current systems that use texture to search for man-made objects rely on pre-extraction and indexing. This study attempts to use a wavelet transform approach to retrieve industrial complexes from aerial photographs of Buffalo, New York. A Haar wavelet transform is applied to database images and search icons. The wavelet transform produces a series of statistical indices that represent texture properties of the images. The statistics of the search icon are compared to the statistics of all database images and the ten database regions with the greatest similarity are retrieved. This study explores the utility of image texture for retrieval of industrial complexes. Texture is evaluated through retrieval performance. A 50-90% retrieval accuracy is demonstrated.*

INTRODUCTION

The production of digital spatial data has increased dramatically in the last decade. This volume of data production has created a need to develop systems that can efficiently store and retrieve digital data to facilitate the use of this information. Image retrieval systems have been increasingly used to meet this need.

The purpose of image retrieval is to find images in a database that are visually similar to a sample image or query icon. Retrieval systems can operate on large databases and allow retrievals to be performed on a variety of image properties such as texture and geometry (Castelli, 1998; Sheikholeslami et al., 1997; Manjunath and Ma, 1996). The content of the retrieval can be land use, structures or anything contained within a set of digital images that has a distinguishable texture or shape.

The potential utility of retrieval systems has been demonstrated in web based applications. Digital libraries have been created which query spatially indexed data such as map and satellite images (Smith, 1996; Baxter and Anderson, 1996). Such systems have been successful in identifying and retrieving various land cover types and urban areas using texture based wavelets.

In general, searches in image retrieval systems are conducted at two different levels of abstraction - semantic and feature vector (Castelli, 1998). In semantic level searches objects are pre extracted and indexed (Castelli, 1998). A semantic object can be defined as any part of an image to which a semantic label can be assigned, such as building or road. A feature vector level search is one that relies on statistical measures of the image produced by applying a wavelet transform. This approach uses sample images of known land-use/land-cover types to retrieve similar images from an image database. Generally, areas not defined as objects, such as a forest, are searched for at the feature vector level because they have uniform texture.

Texture in digital images is related to properties such as shape, pattern, edges, tone and pixel size (Avery and Berlin, 1992; Lillesand and Kiefer, 1994). In an aerial photograph, texture reflects the incongruous pattern of the natural and built environment and usually requires a large areal extent to reveal a texture pattern. Therefore, texture-based wavelets applications have been successful in identifying landuse/land-cover types that have a large areal extent. Texture in the retrieval system is captured in statistical indices that are produced by applying a wavelet transform to all images in the database. A user interface provides a pictoral list of images termed "query icons" that can be used to search the database (Baxter and Anderson, 1996). The texture indices of the query icon are searched against all indices in the database.

This study attempts to use a texture based wavelet transform to retrieve discrete, industrial complexes from urban images. Unlike land-use/land-cover types, industrial complexes may not cover an aeral extent large enough to reveal a texture pattern. The use of wavelet transforms for this approach has not been well investigated. Industrial complex types have not been pre-extracted and indexed. The retrieval relies on texture properties of the image only to search for industrial complexes. Bian (2003) accomplished a 60 to 90 percent retrieval accuracy for industrial complexes by using a Haar wavelet emphasizing the edge pixel statistics of images.

METHODS

Study Area

The Buffalo area has a rich diversity of building types due in part to the industrial history of the city. Buffalo's location on the Great Lakes has been an important factor in shaping the city's character. Shortly after the completion of the Erie Canal in 1825, Buffalo experienced rapid population growth that was accompanied by an increase in trade and industry. The result was a bustling urban center. By 1901, the year of the Pan-American Exposition, Buffalo was the fifth largest city in America. In the 1940's Buffalo was a center for industries including iron and steel production, grain milling, and chemical production. Although most of these industries have left the area in recent years, such buildings still mark the Buffalo landscape.

Database Creation

Aerial photographs of Buffalo, New York at a scale of 1:6,000 were used in this study. One hundred and twenty, nine-inch aerial photographs covering the entire City of Buffalo were scanned as black and white images at a resolution of 600 dpi. Images were saved as Graphics Interchange Format (GIF) files and converted to portable gray map format (PGM). The GIF format is simple, and designed to compress image data to reduce transmission time. A PGM file is a simple grayscale Unix file format used by the retrieval system. These files are not compressed and only one value is stored for each pixel.

To evaluate retrieval performance, a master key was created that identified industrial complexes on the aerial photographs. This was done using parcel information, street maps, and personal knowledge of the study area.

Table 1. Topological and typological attributes for typical Buffalo industrial complexes.

Topological Element	Typological Element
*bounded by parking lots	*rectangular shape
*located near water	*flat roofs
*contain driveways	*smoke stacks
*distant from residential areas	*building complexes
*overlapped by railroads	* grain silos

Query Icons and Texture

Using a texture-based wavelet to retrieve industrial complexes in a digital image database is a difficult challenge. Generally texture in images is applied to different land cover types such as forest, agriculture and water which are uniform in texture. These types of texture patterns extend over large areas. The texture of a discrete industrial complex, in contrast, may be quite small and may contain multiple patterns. Industrial areas may not cover an area large enough to reveal a single texture pattern. Before applying the wavelet application it is necessary to gain an understanding of what components of industrial complexes combine to create texture. A visual examination of known industrial complexes was conducted, to determine an appropriate pixel size for query icons, and to aide in evaluating the utility of image texture and the results of the wavelet application. To do this a framework of topology and typology was created to identify the components of an industrial complex that ultimately reveal texture (Hofmeier, 1999).

Industrial complexes have distinct spatial and physical characteristics. In this study, topology describes the spatial relationship between objects in a complex. For example, objects such as roads, driveways, and parking lots are typically parts of industrial complexes, with typical spatial relationships forming certain patterns. Topological relationships between roads and industrial complexes can be represented by edge relationships. In contrast, a typology classifies objects into categories based on physical attributes. Typological elements are created by the architectural style of individual buildings, which is related to functionality. For example, industrial complexes often have long rectangular roofs.

The Buffalo waterfront is lined with buildings from various types of industry that were constructed over the past seventy years. Although the function of industrial complexes along the Buffalo waterfront is variable, they share several common typological and topological characteristics. These attributes are presented in Table 1.

To search for industrial complexes using a texture based wavelet approach, a unique texture pattern must be identified. Elements of topology and typology create differences in tone, contrast and edges in aerial photographs. These elements are used

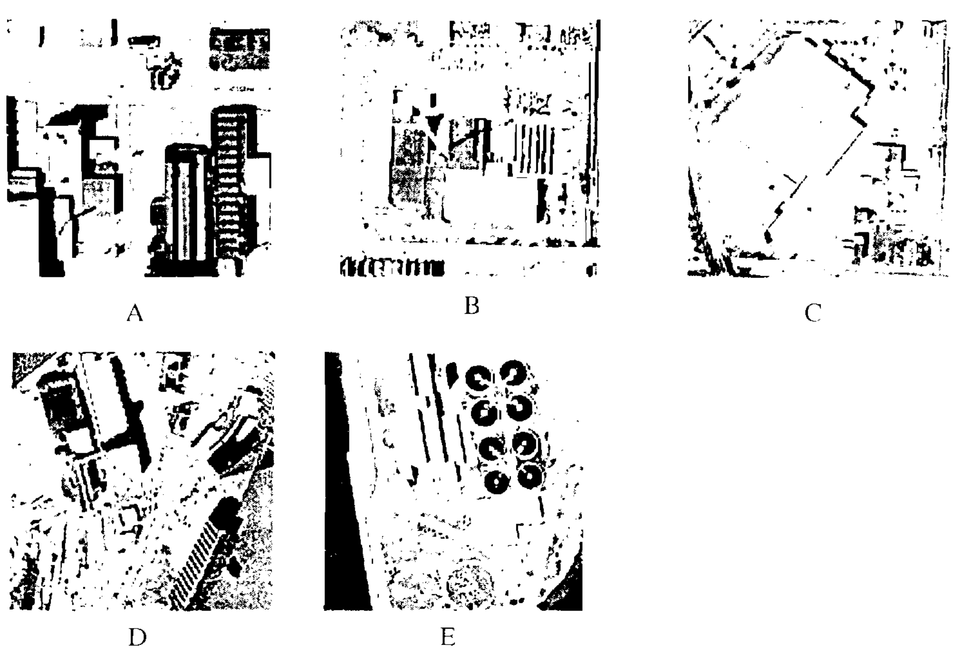


Figure 1. Query icons for industrial complexes at 128x128 pixels.

to aide in delineating query icons, but are not employed in the retrieval process. It is hypothesized that the grouping of these attributes will create a unique texture signature allowing for successful retrieval of industrial complexes from the image database.

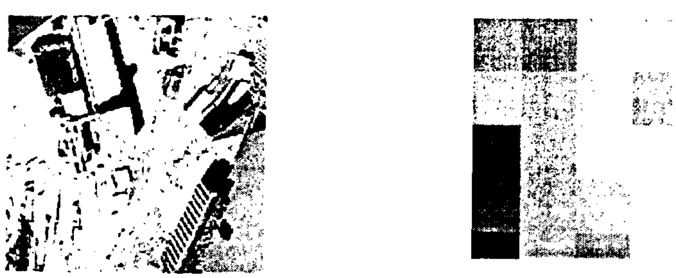
The image database was visually examined for industrial complexes based on knowledge of the area. Five industrial complex sites were selected to be used as query icons (Figure 1). These complexes were chosen because they account for some of the variation in industrial complex types using the topologic and topologic elements. Industrial complex texture can range from coarse to smooth depending on the complexity of the structure and related typological and topological elements. Industrial complexes composed of one large building surrounded by paved area produce a smooth texture, such as query icon "C". Industrial complexes with several different buildings and other typological elements have rough textures, such as query icon "D". This variation results in different sets of statistical indices produced by the wavelet transform. Therefore, one industrial complex icon is not expected to retrieve every industrial complex within the database.

The concepts of typology and topology also aid in selecting an appropriate operational size for the query icons. Bian (1997) describes operational scale as the scale at which a phenomenon operates or can be recognized. Intuitively, industrial complexes operate on a much larger surface area than other types of urban buildings. To accommodate operational scale, which includes typological and topological elements; industrial complex icons were cut at 128x128 pixels; representing a real world area of 10 acres (4.04 ha).

Wavelet Transform

"Wavelets are a mathematical tool for hierarchically decomposing functions" (Stollnitz et al., 1995 p.1). The function can be an image, a surface, a curve or a signal. The utility of the wavelet is that it shows the different levels of detail present in the function. In simpler terms, wavelets allow us to see both the forest and the trees. Wavelet transform has been widely used in remote sensing to smooth images or remove the "noise" from images (Horgan, 1989). Noise is the detail which contaminates the true image. GIS professionals encounter data that has been processed with wavelet transforms when downloading orthophotos, terrain models and satellite data via the web. Many of these data types are in MrSid (Multi-resolution Seamless Image Database) file format. MrSid, developed by LizrdTech corp. uses a type of wavelet to compress the size of these large images to speed transmission time over the web without sacrificing the quality of the image. Image compression using wavelets involves the discarding of some of the unnecessary information while still retaining the major features of the image.

To understand how wavelet transform works, it is necessary to understand the composition of a digital image. Digital images consist of a series of pixels and each pixel is represented by a number



(a) (b)

129	120	158	148
142	133	153	131
97	131	149	168
99	128	137	169
52	134	123	173

(c)

Figure 2. Composition of digital images. (a) original 128 row X 128 column digital image. (b) enlargement showing a 5 row x 4 column area of pixels in the vicinity of the white box in (a). (c) individual DNs corresponding to pixels in (b).

that characterizes the intensity or brightness of the pixel. These pixel values are referred to as Digital Numbers (DNs). Figure 2(a) shows query icon D composed of 128 rows and 128 columns of pixels. In this image the individual pixels are impossible to discern. Figure 2(b) shows an enlarged 5 row by 4 column area of Figure 2a indicated by the white box located near the center of the image. Figure 2c shows the individual DN values corresponding to each pixel in 2b. Figure 2 is a grayscale image and as such DNs range from 0 to 256. A DN of 0 is usually taken to be black and a DN of 256 is typically white (Lillesand and Kiefer, 1994).

Wavelets can represent a single image simultaneously at many different scales. The basic function of a wavelet transform is to perform a filter function on an image by averaging and differencing the DNs. A one-level wavelet transform results in an approximation sub-image and three detail sub-images. The resultant digital values are coefficients of sub-images based on digital numbers. The approximation sub-image maintains the major trend of the original image, while the detail sub-images represent the difference between the approximation sub-image and the original image in different directions; horizontal, vertical and diagonal (Bian, 2003). Different wavelets have different filter methods. This system uses a two-level Haar wavelet transform. The Haar wavelet has several benefits. It is conceptually simple, fast, and the original image can be reconstructed by reversing the process, i.e. no information is lost in the transform. The Haar transform is an average filter based on the average of two adjacent (non-overlapping) pixels. Each pair of

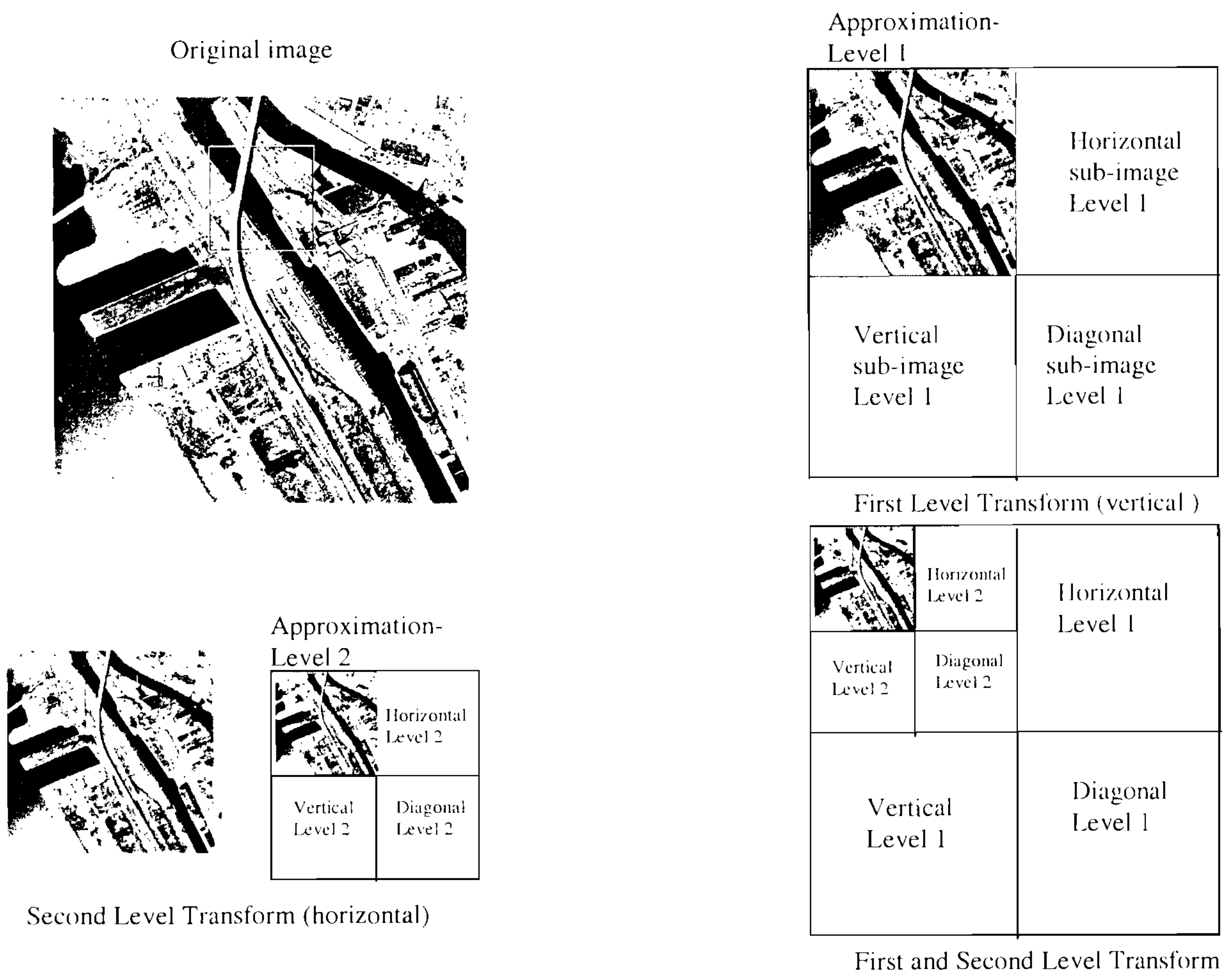


Figure 3. Illustration of a two-level Haar wavelet transform.

Table 2. Results of industrial complex icon retrieval.

Industrial complex Query Icon	Number of matches out of 10 retrievals (Hits)	Rank of Icon out of the ten retrievals.
A	5	1
B	7	1
C	6	Not retrieved
D	9	1
E	5	5

adjacent pixels is averaged and the average value is recorded in the approximation sub-image. The difference between the original and average values is recorded in the detail sub-image. Repeating this process recursively on the averages provides the overall average or approximation of the original image (Stollnitz et al., 1995). This technique is shown below in a four pixel example. Note that no information has been gained or lost in the transform. The original image and the transform image both have four pixels or coefficients. The transform image is composed of the overall average of the original image [5] followed by the detail coefficients in order of increasing resolution.

Original Image	Approximation sub-image	Detail sub-image
[8 4 3 5]	[6 4]	[2 -1]
	[5]	[1]

Transform of original image is :[5 1 2 – 1]

The Haar wavelet uses a rectangular sample window. The first pass uses a window of two pixels (as in the example above) and the width is doubled with each consecutive pass. Figure 3 provides an illustration of a two-level Haar wavelet using a 512x512 aerial photograph of Buffalo, NY. To complete a two-level Harr wavelet transform two passes are required and the width of the second pass uses a four pixel window. In the first pass, the filter is applied along the horizontal direction or rows of pixels, producing an approximation and detail sub-images. In the second pass, the filter is applied along the vertical direction or columns of pixels to both the approximation and the detail sub-images. The resulting approximation and detail sub-images are a quarter of the original image. Because the Harr wavelet is generated on information from pixels that are direct neighbors, it provides ample high and low frequency response which should be adequate to represent industrial buildings that contain both high and low frequency components.

The advantage of applying a two-level Harr wavelet is that it creates a multi-level representation of the original image and detail sub-images at coarser resolutions. This method separates trends in the image from detail and presents the information at multiple scales. Multiple scaling allows the level of change from one resolution to the next to be seen. Statistical indices of mean, standard deviation and number of edge pixels are used to summarize the wavelet coefficients in the approximation and detail sub-images.

RESULTS

The database is searched by comparing statistical indices of the query icon to the statistical indices of all images in the database. Search results are ranked in order of similarity to the query icon based on closeness of the indices. Only the first ten retrievals for each of the five icons were examined in this study. By using this type of approach it is assumed that the statistical indices are representative of the semantic content of the image. However, a retrieved image that is statistically close to the query icon does not guarantee that it is a semantic match. To assess accuracy the ten retrieved images are visually compared to the master key. A match is considered correct if an industrial complex is present in half of the retrieved image. Retrieval performance is based on the number of visually correct matches out of ten retrievals.

Performance = # of correct matches/ 10

The retrieval results for the five query icons are presented in Table 2. Each of the industrial complex icons retrieved between five and nine matches. Thus a 50% to 90% retrieval accuracy is demonstrated. Three of the icons retrieved themselves as the first match. Figure 4 shows the retrieval results for industrial complex icon "D" This icon had a 90% retrieval performance.

DISCUSSION

Initial results for industrial icon retrieval using the Haar wavelet transform approach are promising for several reasons. This study is successful in retrieving discrete objects as opposed to retrieving large-scale texture patterns relating to land use. Industrial complexes are specific objects with specific functions. It also demonstrates that this type of urban object appears to have a unique texture despite the small scale. Capturing typology and topology in the query icon appears to identify a unique texture for industrial complexes. Using this methodology, it may be possible to isolate other man-made objects from digital data sets using wavelet transform techniques. The success of industrial complex retrieval depends on a number of factors including image texture and icon scale. At the current scale of the air photos industrial icons at 128X128 pixels are large enough to contain a unique texture and perform adequate searches.

Incorrectly retrieved images often contained apartment complexes and housing projects which exhibit a mix of building shapes, sizes, and parking areas, not unlike industrial complexes in shape, but very different in function. Query icons B and C retrieved images with parking lot space because these icons themselves contain more parking area than the other icons. In these cases the incorrect matches were acceptable because at least some portion of the icon was retrieved. Parking lots are more likely to have a uniform texture like land use/ land cover which is picked-up by the transform process.

The wavelet approach could also be used to retrieve other urban objects, such as schools and churches, but it is necessary to have the appropriate scale aerial photographs. At the current scale of 1:6,000, it is difficult to isolate churches and schools in the context of a residential background.

Improvement in the retrieval of industrial buildings may be achieved in several ways. Alternative types of wavelet transforms should be tested. The effectiveness of wavelet transform varies from one type of application domain to another. Given the geometric properties of buildings, retrieval may be improved by utilizing wavelet transforms that are geometrically based. Bian (2003) has shown that enhancing the edge information of images through the wavelet transform results in an effective search for industrial complexes.

Content based image retrieval has great potential and broad applications. This application can also be used with digital orthophoto quadrangles and satellite images. With continuing increase in the production of spatial data sets, these systems will become an important means of accessing and utilizing data. These systems must continue to be refined, so that data storage, manipulation and utility are enhanced, and the full potential of image retrieval can be realized.

ACKNOWLEDGEMENTS

The author would like to thank Zongxiang Yang for his efforts to prepare the software and Ling Bian's effort in supervising this project. The anonymous reviewers provided insightful comments and suggestions for this manuscript.

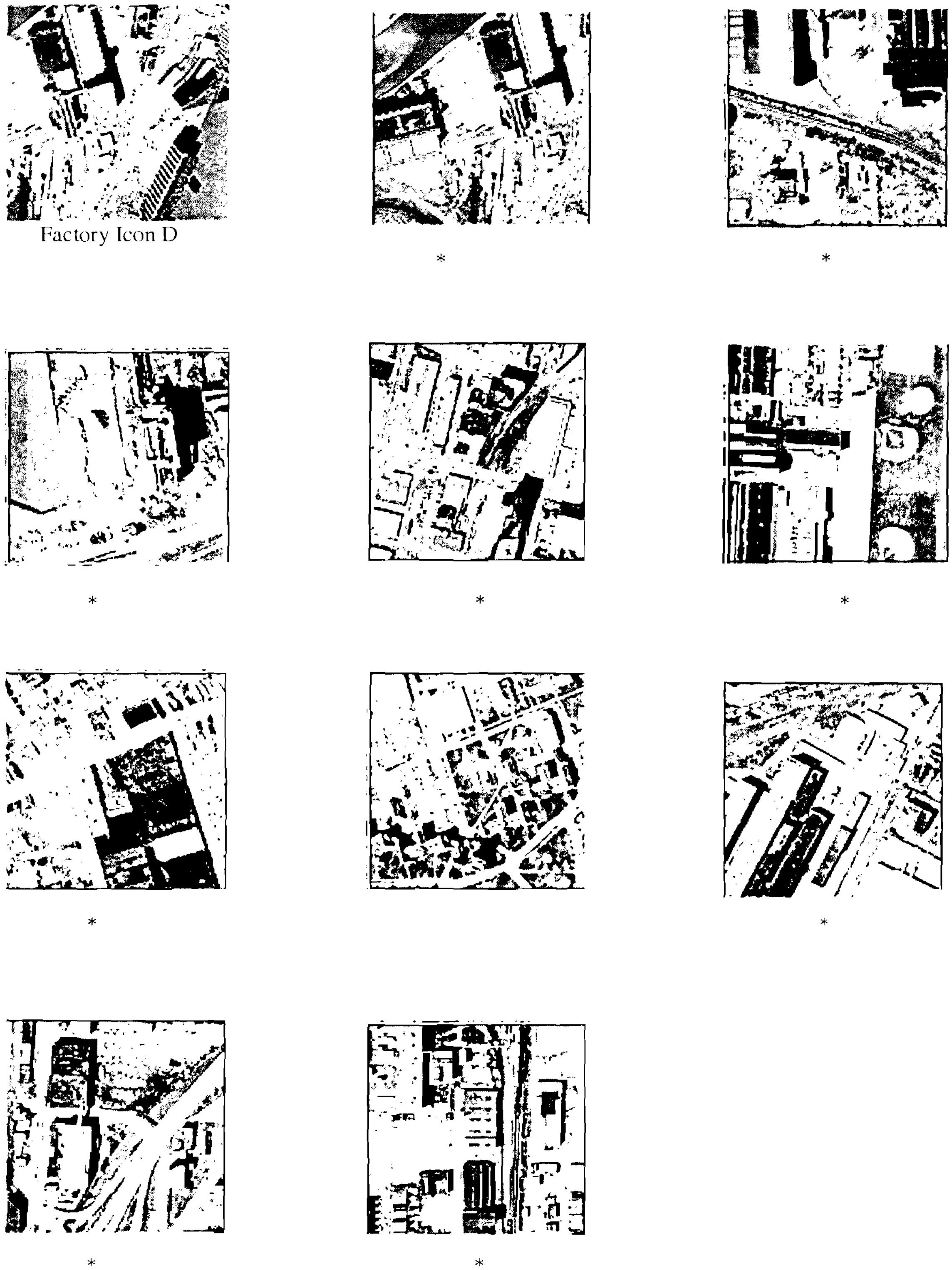


Figure 4. Retrieval results for industrial icon D. A single "*" indicates a match.

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