Evaluation of contents based image retrieval methods for a database of logos on drug tablets

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ABSTRACT

In this research an evaluation has been made of the different ways of contents based image retrieval of logos of drug tablets. On a database of 432 illicitly produced tablets (mostly containing MDMA), we have compared different retrieval methods. Two of these methods were available from commercial packages, QBIC and Imatch, where the implementation of the contents based image retrieval methods are not exactly known. We compared the results for this database with the MPEG-7 shape comparison methods, which are the contour-shape, bounding box and region-based shape methods. In addition, we have tested the log polar method that is available from our own research.

For the evaluation of the rotation invariance and general effectiveness of the image retrieval method we used three different tablets, which were digitized in 25 different positions.

From our experiments it appeared that log polar correlation worked well (relevant matches in top positions) for the shape of the logo. However, the problem with this approach is that it takes a huge computing power, and that it is not capable of making fast search indexes based on descriptors of features. The MPEG-7 methods for this database did not deliver all relevant matches in top positions. The QBIC and Imatch software gave better results due to the influence of their effective color descriptors. With one stamp more colors of pills can be manufactured, so comparing on color is not relevant for the shape comparison of the logos. With the MPEG-7 the results improved after preprocessing and segmenting the logo from the background of the pill. After this processing, the contour-shape based method gave similar results as the log polar correlation.

Keywords: MPEG-7, CBIR, forensic, drugs tablets, MDMA, contour-shape

1. INTRODUCTION

At the drugs department of the NFI a large number of illicitly produced tablets, mostly containing MDMA and amphetamine, are submitted for forensic analysis. Information on the chemical composition and the physical characteristics (i.e., diameter, shape, height and weight) and images of the clandestine tablets is available in a database. The illicit manufacturers often make use of punches resulting in tablets that bear an imprint consisting of all sorts of registered trademarks and fantasy figures. In this research a study has been made for different ways of contents based image retrieval of the logos. In Figure 1 an example of a logo on a drug tablet is shown.

2. CONTENTS BASED IMAGE RETRIEVAL (CBIR)

The correlation method for retrieving the images in this database should be easy to use and invariant to rotation, translation and light conditions. The images of the tablets are acquired with a standard camera with a side light source. This approach may result in differences in the images of the logos due to light variations. Another factor that has to be considered is that a tablet itself can be damaged, and the logo is not completely visible anymore. Since the three-dimensional logo is captured with a regular camera, the resulting 2D shadow image has to be compared. The correlation method should be insensitive to these factors.

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Many research groups[1] are working on image retrieval based on contents. Current research is accessing visual materials by use of multimedia in education, entertainment and publishing companies. Other large-scale image databases include newswire collections and collections such as patent and trademark image databases containing over 600,000 images.
These and other large-scale image databases require new techniques and applications for retrieval and have caused new initiatives for improving access to collections of visual materials. The research is focusing on several broad areas: image indexing and classification, image users and image uses and machine methods for image parsing.

Figure 1: Example of a logo on a drug tablet

A concern with image indexing and classification is the appropriateness of text-based methods for materials other than text. Another concern is that we need to index and retrieve the images quickly. For our drug tablets the logos often are signs for brand names or other fantasy figures. At our Institute a text string of what the examiner recognizes in the logo is entered as text in the database. The difficulty with this approach is that different examiners will classify a logo with a different text string. It is well known that this problem exists from literature.[2] Since some logos are similar to text, OCR-methods[3] can also work for these databases. However, in the OCR-case there is a 2-Dimensional image, and we have to deal with shadow images of a 3-Dimensional shape.
In Contents Based Image Retrieval in general, several layers can be distinguished. An overview article can be found on the Internet at http://www.jtap.ac.uk/reports/htm/jtap-039.html.
The current Level 1 CBIR-techniques is query by example. This means for our case that a drug tablet is entered in the system and it has to be compared with the complete database.
A technique that is often implemented is the use of color histograms in images. This method is not relevant in this approach, since the same stamp can be used to manufacture tablets with different colors. Texture is another basic visual feature used in contents-based retrieval systems. Texture similarity can be useful when distinguishing areas with similar color. A variety of techniques have been used which takes into account the contrast, coarseness, directionality and the randomness.[4,5] However, for our drug tablets we would like to compare logos and often these do not contain texture.
We would like to retrieve the logos by shape. Two main types of shape features are commonly used:

- Global features (aspect ratio, circularity and moment invariants) [6]
- Local features (consecutive boundary segments)[7]

Other methods for shape matching include elastic deformation of templates,[8] and comparison of directional histograms of edges extracted from the image.[9]
In our case we have a drug tablet with a three dimensional logo where only the 2D-view is available. If there would be a standardized way of digitizing the tablet each time in the same way, this would not be a problem, since the 2D-view is reproducible. This might be the case with known logos where the examiner knows how to position the drug tablet. However, there are also other figures that are not known, and these will be positioned randomly. For dealing with 3D-images that are acquired with a 2D-image, there is research available of plausible 3D-models from the 2D image.[10]
There is also research by other types of primitive features. This is position in the image or complex transformations of images as with wavelets or fractals.
The Level 2 system of CBIR will classify the image automatically and then search based on the text string (e.g. OCR). Level 3 systems will recognize on more subjective grounds; however, research in this area is rare. These methods are not evaluated in this research.

3. IMPLEMENTATIONS

To demonstrate the feasibility of new techniques, many experimental systems have been developed by research institutes and by commercial manufacturers.

3.1 Commercial Systems

The most well known commercial database is QBIC of IBM. The system extracts and stores color, shape and texture features from each image in a database, and uses R^*-tree indexes to improve the search speed.[11] This database is available on the web. When searching for an image, the system matches the features from the query and stored image and displays similar images on the screen as thumbnails. An evaluation copy is available from the web at http://wwwqic.almaden.ibm.com. Virage[12 13] and Excalibur[14] are other well-known commercial systems.
The system Imatch is a system at the low-end part of the market that can be downloaded from the Internet at http://www.mwlabs.de/, and there is an evaluation version available for download. A disadvantage for evaluation of these commercial systems is that there is no source code available and the algorithms that are implemented are often not described in literature or patents.

3.2 Developments by Research Institutes

Initiatives that have the source code available on the web include Photobook[8] (http://www-white.media.mit.edu/vismod/demos/photobook). This system is also known for its face comparison features.
The University of Singapore had a research project[15] for CBIR on trademarks where Fourier Descriptors and Moment Invariants measure features of logos. Since the logos in our database often contain trademarks, this research is similar to our approach.
In the past we have tested the Fourier Descriptors and Moment Invariants with neural networks for the shape of profiles in shoeprints.[16] However, in the meantime many other methods have become available. Currently, we are working on a project together with the University of Amsterdam for implementing the database in PicToSeek.[17] This project is also related to trademark retrieval.

3.3 MPEG-7

MPEG-implementations are a standard for video and audio compression, and they are used in a wide variety of equipment and on the Internet. Where MPEG-1, MPEG-2 and MPEG-4 focused on coding[18] and compression, MPEG-7[19] is emerging as a new standard for searching in video and audio streams. The source codes of the algorithms and the test environment are available. The MPEG-7[20] does not define a monolithic system for content description but a set of methods and tools for the different steps of multimedia description. It will standardize: the set of descriptors, the set of description schemes, a language to describe description schemes and one or more methods to encode descriptions. MPEG-7 is developed for Audio and Video. It contains all descriptors as color, shape texture and others. In the current standard three shape descriptors are applied: object bounding box, region-based shape and contour-based shape. It is known that MPEG-7 is a framework that develops rapidly, so many other methods can be implemented in this framework in the future.

3.3.1 Object bounding box

The object bounding box descriptor addresses the coarse shape description of visual objects. A bounding box of a visual object is the tightest rectangular box that fully encompasses that visual object such that the faces/sides of the box are parallel to the principal axis of that object. The descriptor can describe bounding boxes for 2D and 3D objects.
The descriptor consists of three parts. The first part describes the size of the bounding box itself. This portion is rotation and shift invariant. The size is described in normalized coordinates, such that the description is resolution independent.
The second part is the density of valid samples in an object's bounding box and serves as a confidence measure for this descriptor. It can be used to compute the area of a 2D object or the volume of a 3D object.
The third part is optional and describes the spatial position of the visual object in 3D coordinate axes and its orientation.
The extraction of objects consists of three parts:

- Segmentation (just a simple kind of segmentation with labeling pixels)
- Extraction of the bitmap of the object of interest

- Estimating the bounding box

The process of estimating the bounding box is broken down:

- Estimating the orientation of the object (computing Eigen vectors of the tensor of inertia of the object. The object is in a binary format.)
- Normalizing the units

The matching process in general works as follows:

- Compute the descriptors of all images in the database and of the image that is queried for
- Compute the distance between the different descriptors for each image
- Sort the distance in ascending order
- Present the top results in the sorting to the user

3.3.2 Region-based Shape

The region-based shape of a subject will consider the lack of perfect segmentation processes. The region-based descriptor cannot only describe diverse shapes efficiently in a single descriptor and it is robust to minor deformation along the boundary of an object. This method is used for trademark retrieval.

The process consists of:

- Extraction of vertices (segmentation, extraction of the bitmap of object of interest, estimation of a closed contour and encoding of the polygon vertices)
- Determination if a given point is inside or outside the figure represented by the vertices

3.3.3 Contour based Shape

Contour-based shape descriptors capture characteristic shape features of an object or region based on its contour. It uses the Curvature Scale-Space representation, which captures perceptually meaningful features of the shape.

The representation in Curvature Scale-Space has the following properties:

- It captures the characteristic features of shape
- It reflects properties of the human visual system
- It is robust to partial occlusion of the shape
- It is robust to perspective transformations
- It is compact

The process of CSS detection is as described by Mokhtarian.[21] The representation of the contour shape is very compact, below 15 bytes in size. The object itself describes a closed contour of a 2D object or region in the image.

The descriptor itself is composed out of:

- The number of peaks in the image
- The highest peak height
- $$circularity = \frac{perimeter^2}{area} \qquad \textbf{(1)}$$
- $$eccentricity = \sqrt{\frac{0.5(i_{20}+i_{02})+0.5\sqrt{i_{20}^2+i_{02}^2-2i_{20}i_{02}+4i_{11}^2}}{0.5(i_{20}+i_{02})-0.5\sqrt{i_{20}^2+i_{02}^2-2i_{20}i_{02}+4i_{11}^2}}} \qquad \textbf{(2)}$$

  Where $i_{02}=\sum(y-y_c)^2; i_{11}=\sum(x-x_c)(y-y_c); i_{20}=\sum(x-x_c)^2$

  And (x, y) is each point inside the contour shape and (x_c,y_c) is the center of mass of the shape.
- Prototype contour curvature vector. This element specifies the eccentricity and circularity of the prototype contour. The prototype contour is defined as the curve smoothed by means of filtering until it becomes convex. The convex contour is obtained by smoothing with the filter parameters corresponding to the highest peak.
- Xpeak, ypeak: parameters of the remaining peaks with reference to the highest peak. They are ordered in decreasing order. Xpeak [i] is the arc-length position and ypeak [i] is the height of the I-th peak. For example, of ypeak [2] = 0.5 this means ypeak [2] = 0.5*ypeak [1].

3.4 Log Polar

In our research for correlation of impression marks on cartridge cases,[22] we have used log polar correlation.[23] This method is rotation, translation and scaling invariant. The method is used for registering different images; however, it can also be used for searching in databases. The factor that is computed for the registration is a measure if the two images match. This method is more time consuming than the methods that have been previously described in this chapter.

By using the invariant image descriptors in place of the original images, it is possible to avoid the problem that correlation results disappear in noise level. One such descriptor is the log-polar transform of the Fourier magnitude, which removes the effect of translation and uniform scaling into depended shifts in orthogonal directions.[24]

In order to demonstrate the properties of this triple invariant image descriptor, consider the comparison between two images f(x,y) and g(x,y), which are related by a four-parameter geometric transformation:

$$g(x,y) = f(\alpha(x \cos \beta + y \sin \beta) - \Delta x, \alpha(-x \sin\beta + y \cos\beta) - \Delta y \qquad \textbf{(3)}$$

The magnitudes of the Fourier transform are invariant to translation, but retain the effect of scaling and rotation:

$$G'(u, v) | = \frac{1}{\alpha^2} \left| F\left(\frac{u \cos \beta + v \sin \beta}{\alpha}, \frac{-u \sin \beta + v \cos \beta}{\alpha} \right) \right| \qquad \textbf{(4)}$$

Where G (u, v) and F (u, v) are the Fourier Transforms of g (x, y) and f (x, y) respectively.

Mapping of the Fourier magnitudes into polar coordinates (r,θ) achieves the decoupling of the rotation and scale factors; rotation maps to a cyclic shift on the θ-axis, and scaling maps to a scaling of the r-axis:

$$| F'(r,\theta) | = \frac{1}{\alpha^2} \left| F\left(\frac{r}{\alpha}, \theta + \beta \right) \right| \qquad \textbf{(5)}$$

:

Where

$$r = \sqrt{u^2 + v^2} and \theta = \tan^{-1} v / u$$

A logarithmic transformation of the r-axis further transforms scaling into a shift:

$$\left| F'(\rho,\theta) \right| = \frac{1}{\alpha^2} \left| F(\rho - \ln(\alpha), \theta + \beta) \right| \qquad \textbf{(6)}$$

Where ρ=ln(r). The polar mapping followed by the logarithmic transformation of the r-axis is called the log-polar transform.

The optimal rotation angle and scale factor can be determined by calculating the cross-correlation function of the log-polar transformed Fourier magnitudes of the two images. It is important to note that the cross-correlation needs to be circular along the θ-axis, and linear along the ρ-axis:

$$XC(R,T) = \sum_{\rho=\rho_{\min}}^{\rho_{\max}} \sum_{\theta=0}^{2\pi} F(\rho + R, \theta + T) F'(\rho, \theta) \qquad \textbf{(7)}$$

Where F (ρ,θ) is equal to F (F (ρ,θ modulo 2π) and XC(R, T) is the two-dimensional cross-correlation function, with parameters R (difference in logarithm of scale factors) and T (difference in rotation angles).

The θ-axis-circular and ρ-axis-linear cross-correlation can be readily achieved by zero-padding only the ρ-axis direction and performing a circular cross-correlation with an FFT-based algorithm.

If the valid range of rotations is not known a-priori, then an additional cross-correlation may be necessary to remove the 180 degrees ambiguity in the rotation angle, because the Fourier magnitude of a real-valued image is an even function. The correlation factor XC(R, T) is a measure for correlation between the different images.

It is important with respect to the implementation of the triple invariant image descriptor algorithm the choice of the number of samples in the log-polar-domain. This number is based on a realistic memory requirement and a realistic representation in the log-polar-domain.
One way to approach the spatially variant resolution of the log-polar domain is to have the worst-case resolution equal to the log-polar domain equal the resolution in the rectangular domain. The log-polar domain resolution elements are:

$$\Delta\theta = \frac{\Delta l}{r}; \Delta\rho = \frac{\Delta r}{r}$$

Where

$\Delta\theta$: The resolution elements in angular direction
$\Delta\rho$: The resolution elements in logarithm of radius-direction
Δl : the arc length between neighboring points in the rectangular domain
Δr : the resolution element in the radius direction
r : the radius coordinate

The worst-case resolution in the log-polar domain is the minimum value of $\Delta\theta$ and $\Delta\rho$.

4. TEST DATABASE

At our institute a database of images is available of 432 drug tablets that have been submitted as a case to our institute. The database exists of drug tablets from 1992 until now. The database is available on line in QBIC implementation at http://forensic.to/drugstablets.
Furthermore, we have a test set of three drug tablets that have to be searched against. These tablets are acquired in different angles of rotation to determine if the algorithms are rotation invariant. In total we had 25 images for each tablet, so in total we have 432 + 75 images in the database. In figure 3 the three different tablets that we have selected are shown.

5. RECALL OF IMAGES IN THE DATABASE

If we look to the best search reduction we should only find the relevant images in the top position of our search, so we should filter γ[25]:

$$\gamma = \frac{Number\_of\_irrelevant\_images\_in\_the\_database}{Total\_number\_of\_images\_in\_the\_database} \quad \textbf{(8)}$$

For the matching results there are also other measures available in literature (e.g. 17). However, for the experiments we will conduct we will show how many of the images are in the top position of the database and how far in the database the user should search before all images have been found for a particular image.
For the reason that it is not known if the color has been taken into account with the QBIC-database and the Imatch-database, we also compared the results based on color.

6. EXPERIMENTS

It is possible to implement many different Contents Based Image Retrieval Systems. In the scope of this article we limited the number of experiments, and tested the algorithms and software for the test images.

Figure 2: Example of test image Bacar used for the comparison of algorithms. The other images of the playboy-logo and Mitsubishi-logo are not shown in this paper due to copyright laws.

6.1 Plain images

We have tested the different methods with the plain images. The results are shown in Table 1. The first number in these tables is the number of hits in the top positions (25 means all of them). After this a percentage of the database is given that has to be searched until all images are retrieved.

Table 1a: Results with QBIC 3.0 version-database with plain image.

	color	layout	texture	special hybrid
Bacar	25; 5 %	25; 5 %	6; 42 %	25; 5%
Mitsubishi	25; 5 %	8; 14 %	3; 22 %	24, 8 %
Playboy	25; 5%	9; 19 %	15; 22%	22; 14 %

Table 1b: Results with Imatch version 2.1 -software with plain image

	color	layout
Bacar	25	25
Mitsubishi	25	8; 14 %
Playboy	25	9; 19 %

Table 1c: Results with MPEG-7 algorithms (version as available from CVS-host of 15 July 2000)

	ColNonHist	Object Bounding Box	ContourShape	RegionShape
Bacar	24 ; 8 %	23 ; 8 %	1 ; 22 %	4 ; 10 %
Mitsubishu	1 ; 22 %	2 ; 22 %	1 ; 22 %	3 ; 22 %
Playboy	2 ; 22 %	3 17 %	1 ; 22 %	1 ; 22 %

Table 1d: Log Polar comparison

	Default
Bacar	25 ; 5 %
Mitsubishi	23 ; 7 %
Playboy	20; 12 %

From the tables we can determine that the MPEG-7 implementations do not work as well as the QBIC and Imatch implementations for these drug tablets. With the QBIC and Imatch-search systems, the light conditions and color features are used. This explains the reason that all images were found in top positions. The Bacar-tablet has a purple color and there are not many other purple tablets in the database. For this reason this tablet correlates best with color descriptors. The log polar implementation works best on shape. However, this method takes much computing power (for searching the complete database it took several days on a Pentium II 333 Mhz –computer), and there are no indexes that can be easily searched though. For this reason we did pre-processing of the images.

6. 2 Preprocessed Images

Since we would like to have more control on which part of the tablets are compared, it is necessary to segment the image itself in the logo part and the tablet part. The shape of the tablet is also a measure where it can be searched on; however, it is

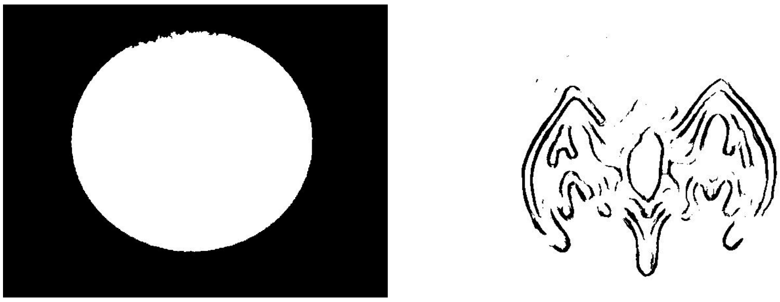

Figure 3: Splitting of shape of pill and logo with the algorithm described

out of the scope of this paper. We segment the logo itself with a standard procedure. The procedure is as follows:

- First normalize the image, then threshold below grey-level 128
- *For finding the shape of the tablet*: label with Euclidean distance metric, 4 Connectivity, with a Split and Merge Factor of 14 percent, and a Minimum Region Size of 27 percent (these values are from analyzing several tablets)
- *For finding the edges of the tablet:* threshold
- *For filtering the edges of the tablet:* make the selection 5 percent smaller
- Then multiply the thresholded and resized image with the image (figure 3, right)
- The final results is the logo (figure 3, left)

In Tables 2a-c the results of this procedure are shown. The log polar method has not been tested with these images.

Table 2a: Results with QBIC 3.0 version-database with plain image (the color search engine fails to operate for b/w images

	color	**layout**
Bacar	failed	1 ; 55 %
Mitsubishi	failed	2 ; 75 %
Playboy	failed	1 ; 63 %

Table 2b: Results with Imatch version 2.1 -software with plain image

	Default	**Fuzzy**
Bacar	2; 80 %	4 ; 67 %
Mitsubishi	6 ; 77 %	10 ; 38 %
Playboy	3 ; 49 %	13 ; 28 %

Table 2c: Results with MPEG-7 algorithms (versions as available from CVS-host of 15 July 2000)

	ColHistNonUniS	**Object Bounding Box**	**ContourShape**	**RegionShape**
Bacar	1; 75 %	1 ; 33 %	25 ; 5 %	4 ; 22 %
Mitsubishu	1 ; 99 %	1 ; 68 %	24 ; 5 %	3 ; 22 %
Playboy	2 ; 45 %	1 ; 75 %	25 ; 5 %	1 ; 22 %

7. CONCLUSIONS AND DISCUSSION

In this research it appeared that the use of contour-based shape that was available in the MPEG-7 resulted in the most optimal results for speeds versus ranking on the hit list. This method uses the Curvature Scale-Space representation, which captures perceptually meaningful features of the shape. The log-polar implementation can also be used. However, this method takes a lot of calculating time, and for the searches no indexes can be calculated so the complete database has to be compared each time.

The color features appeared to work well with our test set. However, in practice this method is not useful since light conditions vary, and also the color of the tablet itself can differ with the same stamp.

The results of this research are limited to the three different test cases and the database of pills that have been used. It is expected that logos of pills that have been damaged severely will not be in the top position.

In future research 3D-images that are acquired by structured light equipment will be tested with different image search algorithms.

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