

Journal of Computer Science and Control Systems

<http://electroninf.uoradea.ro/reviste/default.htm>



ISSN: 1844-6043

University of Oradea Publisher

JCSOS - Journal of Computer Science and Control Systems, Vol. 5, Nr. 2, October 2012



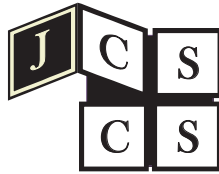
Academy of Romanian Scientists

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CONTENTS

<p>DACHIN Tudor¹, MEZA Serban², NEMES Marian³, VODA Adriana⁴, BADILA Florin⁵ - ¹University “Lucian Blaga” of Sibiu, Romania, ²Technical University of Cluj-Napoca, Romania, ³Continental Automotive Systems S.R.L., Sibiu, Romania, ⁴iQuest Technologies, Cluj-Napoca, Romania, ⁵Wenglor Electronic, Sibiu, Romania Complexity Appreciation for BLDC Flat Top Sinus Implementation.....</p>	5
<p>GOYAL Sumit, GOYAL Kumar Gyanendra - National Dairy Research Institute, Karnal, India Use of Artificial Neural Network for Testing Effectiveness of Intelligent Computing Models for Predicting Shelf Life of Processed Cheese.....</p>	9
<p>HANGIU Radu-Petru, FILIP Andrei-Toader, MARȚIȘ Claudia Steluța, BIRÓ Károly Ágoston - Technical University of Cluj-Napoca, Romania A Z-Source Inverter for an Integrated Starter Alternator.....</p>	15
<p>HARLIȘCA Ciprian, SZABÓ Loránd - Technical University of Cluj-Napoca, Romania Real-Time Simulation Environment for Embryonic Networks.....</p>	19
<p>MARGINEAN Calin¹, MARGINEAN Ana-Maria¹, VESE Ioana¹, TRIFA Viorel¹, TRIFU Emil² - ¹Technical University of Cluj-Napoca, Romania, ²S.C. TRAMBUS S.R.L., Cluj-Napoca, Romania Design and Implementation of a PWM Inverter for Reluctance Motors.....</p>	23
<p>RAMAKRISHNAN Sumathi¹, MAHALINGAM Usha² - ¹Pavai College of Technology, Namakkal, India, ²Sona College of Technology, Salem, India Microstructure Development by Controlling Grain Size.....</p>	27
<p>STOJANOVIC Igor, ZDRAVEV Zoran, TASEVSKI Angel - ‘Goce Delcev’ University, Stip, Macedonia Progressive Wavelet Correlation as a Tool for Recognition of the Images.....</p>	33
<p>VIATTCHENIN Dmitri - National Academy of Sciences of Belarus, Minsk, Republic of Belarus Detecting Outliers in Interval-Valued Data Using Heuristic Possibilistic Clustering.....</p>	39

Progressive Wavelet Correlation as a Tool for Recognition of the Images

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Abstract – An algorithm for recognition and retrieval of image from image collection is developed. Basis of the algorithm is the progressive wavelet correlation. The final result is the recognition and retrieval of the wanted image, if it is in the image collection. Instructions for the choice of correlation threshold value for obtaining desired results are defined.

Keywords: discrete cosine transform; multiresolution; progressive wavelet correlation; recognition; wavelets.

I. INTRODUCTION

Images, drawings, photographs as means of communication among people, for sending and receiving messages have been part of everyday life for a long a time. The easy to use World Wide Web, the reduced price of storage devices as well as the increased calculating power allow an essential and efficient management of large quantity of digital information. All of these factors offer a number of possibilities to the designers of real image-browsing and retrieval systems.

However, image digitalization systems do not allow for an easy management of collections of images. A particular form of cataloguing and indexing is still required. The need for efficient storage and retrieval of images was recognized by managers of large collections of images long time ago and was studied at a workshop sponsored by the American National Science Foundation in 1992 [1]. Data representation, feature extractions and indexing, image query matching and user interfacing were identified as areas with a potential for improvement. One of the issues identified was the problem of locating a picture in a large and diverse collection of images.

The earliest and the most sophisticated descriptor-based image recognition engine is IBM QBIC [2]. Another set of content-based tools for image recognition and retrieving have also improved throughout the years. Examples for such tools are VisualSEEK[3], WebSEEK [4] and ImageRover [5]. ImageRover uses low resolution for image representation in six regions in

order to cover particular information along with the region based descriptors. The present commercially available engines for image recognition, based on descriptors, provide no assurance that the required information from the libraries can be found. For some applications such as for example, collections of medical images or satellite images the even the smallest details can be important. Descriptor based retrieval engines cannot meet satisfactorily such requirement. Reconstruction of details here happens only to a particular level of resolution. In addition large images can contain so many details which cannot be comprised in any compact description.

An alternative approach to the problem set forth above is pixel (elements of digitalized image) based recognition and retrieval. This type of recognition involves analysis of the image. Still this requires intense computing especially when the image contains many subtle details. Despite this fact, the existence of large number of operations per image doesn't seriously restrict the application of pixel-based recognition and retrieval techniques, especially not when it comes to research and experimental purposes.

Pixel-based techniques work by locating a particular pattern in a given image library. Popular criteria for matching are the normalized correlation coefficients [6], which measure the differences between images and patterns from the library. The particular strength of these criteria is that they are insensitive to uniform differences in brightness.

Some of the work done in the area of PWC (Progressive Wavelet Correlation) [6] are outlined in Section 2. Our proposal about applying of PWC for recognition images stored in a database is presented in Section 3. Results of experiments are presented in Section 4.

II. PROGRESSIVE WAVELET CORRELATION

In this section we summarize the technique described in [6], [7]. The fundamental operation for recognition is

the circular correlation $x \otimes y$. The j^{th} entry of the circular correlation is defined as:

$$(x \otimes y)_j = \sum_{i=0}^{N-1} x_{i+j \bmod N} y_i, \quad j = 0, 1, \dots, N-1 \quad (1)$$

where x and y are column vectors of length N . The matrix form is $x \otimes y = Xy$, where X is left circulant matrix generated by x :

$$X = \begin{bmatrix} x_0 & x_1 & \dots & x_{N-1} \\ x_1 & x_2 & \dots & x_0 \\ \dots & \dots & \dots & \dots \\ x_{N-1} & x_0 & \dots & x_{N-2} \end{bmatrix}. \quad (2)$$

The notation $(P)_{i \downarrow R}$ denotes subsampling of P by taking components whose indices are equal to i modulo R . For example, if $R = 4$ and $i = 2$, the subsampling operation extracts the elements 2, 6, 10, 14, ... from P . Progressive wavelet correlation using Fourier methods is based on four theorems: the Wavelet-Correlation Theorem, the Fourier-Wavelet Correlation Theorem, the Fourier-Wavelet Subband Theorem and the Fourier-Wavelet Multiresolution Theorem. To simplify the discussion all data are assumed to be one-dimensional vectors.

Wavelet-Correlation Theorem:

$$(x \otimes y)_{0 \downarrow R} = \sum_{k=0}^{R-1} ((Hx)_{k \downarrow R}) \otimes ((Hy)_{k \downarrow R}) \quad (3)$$

where H is wavelet-packet transform. \otimes is the Kronecker product of I_M and W , $H = I_M \times W$, where I_M is $M \times M$ identity matrix and W is an $R \times R$ matrix with property $W^T W = I_R$. The wavelet transform packet matrix H has a special structure. H is block diagonal with block size R . For instance, W can be 2×2 Haar matrix:

$$W = \left(\frac{1}{\sqrt{2}} \right) \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}. \quad (4)$$

Fourier-Wavelet Correlation Theorem:

$$\begin{aligned} & (x \otimes y)_{0 \downarrow R} = \\ & = F_M^{-1} \left(\sum_{k=0}^{R-1} (F_M ((Hx)_{k \downarrow R})) * (\hat{F}_M ((Hy)_{k \downarrow R})) \right) \end{aligned} \quad (5)$$

where F_M is the Fourier transform matrix of dimension M and \hat{F}_M is the complex conjugate of F_M .

Fourier-Wavelet Subband Theorem:

$$F_N x = (T_{N,M,R} H^{-1}) (F_{M,R} H x) \quad (6)$$

where $N = MR$. The matrix $F_{M,R}$ is an interlaced Fourier transform matrix with structure $F_{M,R} = F_M \times I_R$, that is it has R interlaced copies of transform of size M . The matrix $T_{N,M,R}$ is a Fourier update matrix that transforms $F_{M,R}$ into F_N : $F_N = T_{N,M,R} F_{M,R}$.

Fourier-Wavelet Multiresolution Theorem:

$$\begin{aligned} & F_{N/R,R} H_1 x = \\ & = (T_{N/R,N/R^2,R} \times I_R) U_{2,1}^{-1} F_{N/R^2,R^2} H_2 x \end{aligned} \quad (7)$$

$$F_N x = T_{N,N/R,R} H_1^{-1} (T_{N/R,N/R^2,R} \times I_R) U_{2,1}^{-1} F_{N/R^2,R^2} H_2 x \quad (8)$$

where $N = MR^2$. H_2 is a coarse transform matrix that is block diagonal with block of size R^2 with the structure $H_2 = I_{N/R^2} \times (W_1 \times W_1)$ and operates on R^2 subbands, each of length N/R^2 . W_1 is an $R \times R$ wavelet filter matrix with property $W_1^T W_1 = I_R$. H_1 is a fine transform matrix that is block diagonal with block size N/R with structure $H_1 = I_{N/R} \times W_1$. There is an update matrix $U_{2,1}$ that refines H_1 into H_2 , $H_2 = U_{2,1} H_1$. The matrix $U_{2,1}$ is block diagonal with block of size R^2 with the following structure:

$$U_{2,1} = I_{N/R^2} \times (W_1 \times I_R) \quad (9)$$

III. METHOD FOR IMAGE RECOGNITION

JPEG compression is based on the discrete-cosine transform (DCT) [6]. The matrix C_8 is an 8×8 DCT matrix that is used to create transforms of 8×8 subimages in a JPEG representation of an image.

The multiresolution recognition process relies on the factorization of the DCT matrix $C_8 = V_{8,4} V_{4,2} V_2$, where V_2 and $V_{4,2}$ are matrices built from Kronecker products of W and the identity matrix.

The matrix $V_2 = I_4 \times W$ consists of 4 interlaced copies of W and is of size 8×8 . The matrix $V_{4,2}$ has a structure $V_{4,2} = I_2 \times (W \times I_2)$.

If we write $C_8 = V_{8,4} V_{4,2} V_2$ where $V_{8,4}$ is a matrix whose coefficients we want to compute, then

$$V_{8,4} = C_8 V_2^{-1} V_{4,2}^{-1} \quad (10)$$

obtain the last expression by multiplying both sides by $V_2^{-1} V_{4,2}^{-1}$. The matrix $V_{8,4}$ satisfies equation $V_{8,4} =$

$V(W \times I_4)$. The inverse of V is given by (11), where $\gamma(m) = \cos(2\pi m/32)$.

$$V^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma(2)\gamma(7) & 0 & \gamma(5)\gamma(6) & 0 & \gamma(3)\gamma(6) & 0 & \gamma(2)\gamma(1) \\ 0 & \gamma(6)\gamma(1) & 0 & \gamma(3)\gamma(2) & 0 & -\gamma(5)\gamma(2) & 0 & -\gamma(6)\gamma(7) \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & \gamma(2)\gamma(1) & 0 & -\gamma(3)\gamma(6) & 0 & \gamma(5)\gamma(6) & 0 & -\gamma(2)\gamma(7) \\ 0 & 0 & \gamma(6) & 0 & 0 & 0 & \gamma(2) & 0 \\ 0 & 0 & \gamma(2) & 0 & 0 & 0 & -\gamma(6) & 0 \\ 0 & -\gamma(6)\gamma(7) & 0 & \gamma(5)\gamma(2) & 0 & \gamma(3)\gamma(2) & 0 & -\gamma(6)\gamma(1) \end{bmatrix} \quad (11)$$

The matrix H is an $N \times N$ matrix with the structure $I_M \times C_8$ where $N = 8M$. It produces the JPEG transform of a vectors of length N . Let x be image stored as a JPEG transform of a vector Hx with an instance of a pattern y with JPEG transform Hy . The algorithm consists of three incremental steps, each of which quadruples the number of correlation points. The three incremental steps are:

1. *Coarse correlation* – Generate the Fourier transforms $F_{M,8}Hx$ and $\hat{F}_{M,8}Hy$. Multiply the transforms point by point and partition them into eight subbands of length M . Add these eight vectors and take the inverse Fourier transform of the sum. Every eighth point of the correlation is generated.
2. *Medium correlation* – Multiply $F_{M,8}Hx$ by $(T_{2M,M,2} \times I_4)(I_M \times ((W \times I_4)V^{-1}))$ and $\hat{F}_{M,8}Hy$ by $(\hat{T}_{2M,M,2} \times I_4)(I_M \times ((W \times I_4)V^{-1}))$. Multiply the resulting vectors point by point and partition them in four subband of length $2M$. Add the subbands and you will create a single vector of length $2M$. Taking the inverse Fourier transform of size $2M$ yields the correlation at indices that are multiples of 4 mod 8 of the full correlation.
3. *Fine correlation* – Multiply the x and y transform from the preceding step by $(T_{4M,2M,2} \times I_2)(I_M \times V_{4,2})$ and $(\hat{T}_{4M,2M,2} \times I_2)(I_M \times V_{4,2})$, respectively. Multiply the resulting vectors point by point and partition them in two subbands of length $4M$. Add the subbands and you will create a single vector of length $4M$. Take the inverse Fourier transform of size $4M$ to obtain the correlation at indices that are multiples of 2 mod 8 and 6 mod 8 of the full correlation.
4. *Full correlation* – Multiply the x and y transform from the last step by $I_{8M,4M,2}(I_M \times V_2)$ and $\hat{T}_{8M,4M,2}(I_M \times V_2)$, respectively. Multiply the resulting vectors point by point and take the inverse Fourier transform of size $8M$ to obtain the correlation at odd indices.

Fig. 1 is a flow diagram showing the steps performed for an image recognition according to the PWC method and it is in the Test “block” where one checks whether a particular set of pixels of the given pattern y and image x have similar values. The algorithm can be described as follow:

- Step 1: A candidate image is coarsely correlated with the pattern. Every eighth point of the correlation is generated.
- Step 2: It is determined whether the pattern suitably matches the candidate image. If not, then another candidate image may be chosen or the process abandoned.
- Step 3: If the match was suitable, then the candidate image is medium correlated with the pattern. We obtain the correlation at indices that are multiples of 4 mod 8 of the full correlation.
- Step 4: Another similar match test is performed.
- Step 5: A candidate image is fine correlated with the pattern. Fine correlation means to obtain the correlation at indices that are multiples of 2 mod 8 and 6 mod 8 of the full correlation.
- Step 6: Another similar match test is performed.
- Step 7: Full correlation: obtain the correlation at odd indices.
- Step 8: If a suitable match is found for the fully correlated image, then the image recognised for has been found.

When multiresolution analysis technique is applied to JPEG representation of data, the lowest resolution correlation can be performed directly on the JPEG images to produce 1/64 of the correlation points. The regonition consists of three incremental steps. The process can be halted at any stage if the intermediate results indicate that the correlation will not result in a match.

We investigate what happens in the two-dimensional case. Let the image size be N by N . In step 1, we have 64 subbands of length $N^2/64$. We perform one step of the inverse 2D JPEG transfer function, and one 2D step of the forward Fourier transform function. The next step includes adding the 64 subbands point by point to create a 2D array of size $N/8$ by $N/8$. Taking the inverse Fourier transform, we obtain the correlations at points that lie on a grid that is coarser than the original pixel grid by a factor of 8 in each dimension. In step 2, we obtain 16 subbands of size $N^2/16$ by adding the 16 subbands point by point, and taking the Fourier inverse. We will obtain the correlation values on a grid that is coarser than the original grid by a factor of 4 in each dimension. In step 3, we obtain 4 subbands of size $N^2/4$. Finally, in step 4, the full resolution is obtained.

Formulas for calculating normalized correlation coefficients that measure differences between images and patterns are given in [6]. Normalized correlation coefficients can be computed from the correlations described above. The normalization is very important because it allows for a threshold to be set. Such a threshold is independent of the encoding of the images.

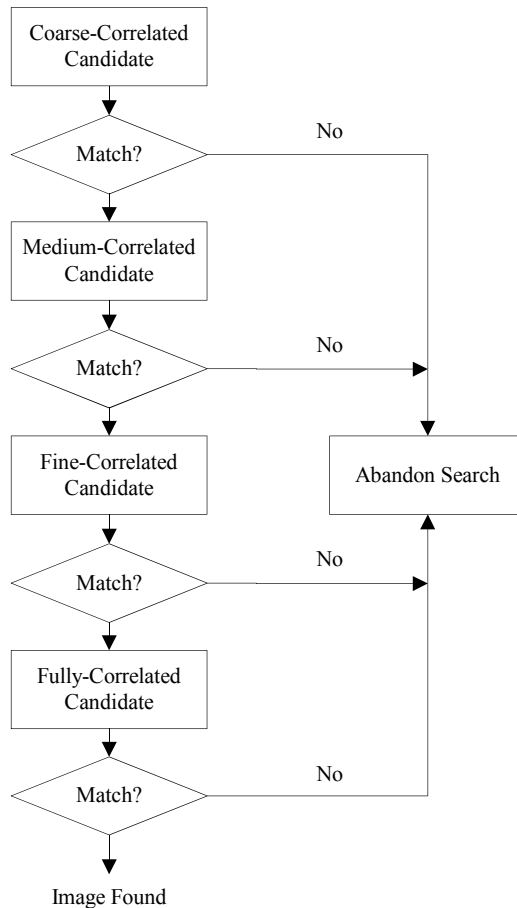


Fig. 1. Flow diagram of PWC method

The normalized correlation coefficient has a maximum absolute value of 1. Correlations that have absolute values above 0.9 are excellent, and almost always indicate a match found. Correlations of 0.7 are good matches. Correlations of 0.5 are usually fair or poor. Correlations of 0.3 or less are very poor.

There is a tradeoff between the value of the threshold and the likelihood of finding a relevant match. Higher thresholds reduce the probability of finding something that is of interest, but they also reduce the probability of falsely matching something that is not of interest.

The progressive wavelet correlation provides guidelines on how to locate an image in the image library. To make this method practical, we must first decide how to store the images. The initial choice is to store them in a disk file system. This can be seen as the quickest and simplest approach. A better alternative that should be considered is to store those images in a database.

Databases offer several strengths over traditional file system storage, including manageability, security, backup/recovery, extensibility, and flexibility.

We use the Oracle Database for investigation purposes. There are two ways of storing an image into the Oracle Database. The first one is the use of Large Objects – LOB, and the second one is the use of Oracle *interMedia*. To store images into the database we use the

BLOB datatype. After creation of one BLOB column defined table we also create a PL/SQL package with a procedure for loading images (named load). This procedure is used to store images into the database. The implementation of the progressive wavelet correlation in Matlab and the connection between the algorithm with the database are the next steps. The Database Toolbox is part of an extensive collection of toolboxes for use with Matlab.

Before the Database Toolbox is connected to a database, a data source must be set. A data source consists of data for the toolbox to access, and information about how to find the data, such as driver, directory, server, or network names. Instructions for setting up a data source depend on the type of database driver, ODBC or JDBC. For testing purposes JDBC drivers were usually used [8].

After setting up the data source for connecting to and importing data from a database we have used several standard functions of the Matlab Database Toolbox. We can retrieve BINARY or OTHER Java SQL data types. However, the data might require additional processing once retrieved. For example, data can be retrieved from a MAT-file or from an image file. Matlab cannot process these data types directly. One needs knowledge of the content and might need to massage the data in order to work with it in Matlab, such as stripping off leading entries added by the driver during data retrieval.

The last step in the adaptation is to create Matlab applications that use the capabilities of the World Wide Web to send data to Matlab for computation and to display the results in a Web browser. In the simplest configuration, a Web browser runs on a client workstation, while Matlab, the Matlab Web Server (matlabserver), and the Web server daemon (httpd) run on another machine. In a more complex network, the Web server daemon can run on a separate machine [9,10].

The practical implementation of progressive wavelet correlation includes two main subsystems: the server sub-system and the client subsystem.

The server subsystem handles the processes of image storing in a database and similarity measure. The client subsystem handles the process of querying. In addition, we present here the system architecture of the system (Fig. 2).

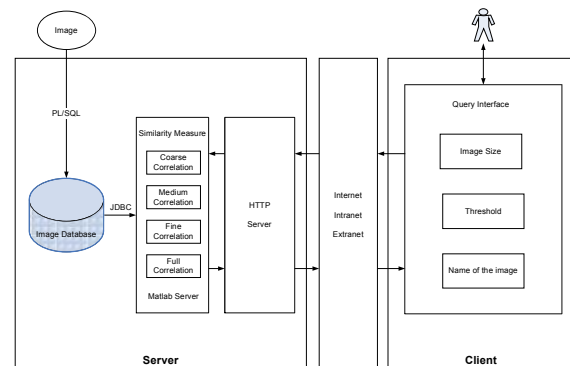


Fig. 2. System Architecture of PWC system

The following query image procedure is proposed:

- Step 1: The user presents the input parameters of the query interface and sends the query message.
- Step2: HTTP Server receives the query message and forwards it to the Matlab Server.
- Step3: The similarity measure mechanism measures the similarity between the query image and the database images comparing the different levels of correlation with the introduced correlation threshold.
- Step 4: The Matlab Server passes to the HTTP Server all the images candidates whose correlations along with the query image are larger than the adopted correlation threshold.
- Step5: HTTP Server sends the candidate images of the query interface to the client's site.
- Step6: The user receives the candidate images by means of the query interface.

IV. NUMERICAL RESULTS

This section represents experimental results obtained by means of image retrieval through an algorithm of progressive wavelet correlation.

Different experiments were set up as follows:

- a) The required image is included several times in the database with different names;
- b) The image is included only once in the database;
- c) Aside from the required image, the database also contains an image very similar to the required one (smudged in some parts or an image generally slightly different);
- d) The required image is not present in the database.

The experiments are carried out upon databases including between 250 and 1000 store images. Oracle 10g version 10.1.0.2.0, served as our database, while we used Matlab version is 7.0.4.365 (R14) Service Pack 2 for image recognition.

Two images, called flower01.jpg and flower10.jpg, served as recognized targets. Image flower01.jpg appears eight times under different names in the database, while the image flower10.jpg appears six times. The database contains images that are more visually similar to the image flower10.jpg.

Evaluation of the quality of the system concerning its precision p is estimated using the following definition:

$$p = \frac{|A(q) \cap R(q)|}{|A(q)|} \quad (12)$$

where q stands for query, $R(q)$ signifies a set of relevant images for the query in the database, while $A(q)$ stands for the set of images returned as a response to the set query q .

In the following tables are given precision for different correlation threshold values ranging from 0,2 to 0,7 with step 0,1. The number of images in the database is 1000.

TABLE 1. flower01.jpg.

Threshold	0,2	0,3	0,4	0,5	0,6	0,7 - 1
Retrieved images	761	435	113	19	8	8
Precision	0,01	0,02	0,07	0,42	1	1

TABLE 2. flower10.jpg.

Threshold	0,2	0,3	0,4	0,5	0,6	0,7 - 1
Retrieved images	911	640	285	79	18	6
Precision	0,007	0,009	0,02	0,08	0,33	1

Considering the Tables 1 and 2, it can be concluded that a high accuracy value can be obtained for correlation threshold values greater than or equal to 0,7.

The results presented in the Table 3 and 4 refer to two different images 21.jpg and 40.jpg. Each of these images is included only once in the database.

TABLE 3. 21.jpg.

Threshold	0,2	0,3	0,4	0,5	0,6	0,7 - 1
Retrieved images	879	500	200	37	2	1
Precision	0,001	0,002	0,005	0,27	0,5	1

TABLE 4. 40.jpg.

Threshold	0,2	0,3	0,4	0,5	0,6	0,7 - 1
Retrieved images	854	541	174	27	2	1
Precision	0,001	0,002	0,006	0,37	0,5	1

The next example refers to image 181.jpg. This example is specific because the database contains a similar image 183.jpg with its vertical sides slightly smudged. The similar images are shown in Fig. 3.



Fig. 3. Two very similar images

TABLE 5. 181.jpg.

Threshold	0,4	0,5	0,6	0,7	0,8	0,9 -1
Retrieved images	332	77	3	2	2	1
Precision	0,006	0,03	0,67	1	1	1

It is evident from table that when correlation threshold values are 0,7 and 0,8, both the images 181.jpg and 183.jpg are retrieved. If the correlation threshold is equal to or greater than 0,9 only image 181.jpg is retrieved.

The table below gives the number of retrieved images for different value of the correlation threshold for image 50.jpg, which is not present in the database.

TABLE 6. 50.jpg.

Threshold	0,3	0,4	0,5	0,6	0,7	0,8 -1
Retrieved images	719	412	119	14	2	0

For correlation threshold values greater than or equal to 0,8 there aren't any images retrieved from the database. Therefore if the correlation threshold is set sufficiently high, the system correctly predicts the absence of the image.

IV. CONCLUSIONS

Based on our experience and experimental evidence we conclude that PWC is a useful tool for image recognition and retrieving from databases.

The main feature of PWC is its high accuracy. With the choice of an adequate correlation threshold it is possible to conclude whether the given image is present in the database, whether there are images similar to the required one with different names, whether there are images slightly different from the required one, and whether the required image is actually included in the database.

The examples studied imply that with the selection of a threshold greater than or equal to 0,7 it can be established that the required image is included in the database. Such selection of threshold gives the accurate number of images identical to the required one comprised in the database. With a correlation threshold greater than or equal to 0,9 a slight difference between two very similar images can be ascertained. In our examples, when the minimal threshold value is 0,8 it is established that the required image is not included in the database.

Owing to the large number of operations, the pixel-based methods for image recognition and retrieval are slow compared to commercially available content-based

systems. We believe that in the coming years PWC based methods will be able to achieve detailed analysis of thousands of images per second.

As far as computing progressive wavelet correlation is concerned, the question still to be answered is whether there is an alternative factorization of DCT matrix which will meet the structural requirements and will transfer as many computations as possible from the first into the second and third step in the algorithm.

According to the future researches, focused on the construction of image recognition and retrieval system, regardless of the technique that the system uses, only the issue concerning system quality assessment from the aspect of efficiency and applicability is to be tackled. Retrieval systems should be comparable for the purpose of identifying the good techniques [11].

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