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Image Compression in Face Recognition - a Literature Survey

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1. Introduction

Face recognition has repeatedly shown its importance over the last ten years or so. Not only is it a vividly researched area of image analysis, pattern recognition and more precisely biometrics (Zhao et al., 2003; Delac et al., 2004; Li & Jain, 2005; Delac & Grgic, 2007), but also it has become an important part of our everyday lives since it was introduced as one of the identification methods to be used in e-passports (ISO, 2004; ANSI, 2004).

From a practical implementation point of view, an important, yet often neglected part of any face recognition system is the image compression. In almost every imaginable scenario, image compression seems unavoidable. Just to name a few:

i. image is taken by some imaging device on site and needs to be transmitted to a distant server for verification/identification;
ii. image is to be stored on a low-capacity chip to be used for verification/identification (we really need an image and not just some extracted features for different algorithms to be able to perform recognition);
iii. thousands (or more) images are to be stored on a server as a set of images of known persons to be used in comparisons when verifying/identifying someone.

All of the described scenarios would benefit by using compressed images. Having compressed images would reduce the storage space requirements and transmission requirements. Compression was recognized as an important issue and is an actively researched area in other biometric approaches as well. Most recent efforts have been made in iris recognition (Rakshit & Monro, 2007; Matschitsch et al., 2007) and fingerprint recognition (Funk et al., 2005; Mascher-Kampfer et al., 2007). Apart from trying to deploy standard compression methods in recognition, researchers even develop special purpose compression algorithms, e.g. a recent low bit-rate compression of face images (Elad et al., 2007).

However, to use a compressed image in classical face recognition setups, the image has to be fully decompressed. This task is very computationally extensive and face recognition systems would benefit if full decompression could somehow be avoided. Working with partly decompressed images is commonly referred to as working in the compressed domain. This would additionally increase computation speed and overall performance of a face recognition system.

The aim of this chapter is to give a comprehensive overview of the research performed lately in the area of image compression and face recognition, with special attention brought to

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performing face recognition directly in the compressed domain. We shall try to link the surveyed research hypotheses and conclusions to some real world scenarios as frequently as possible. We shall mostly concentrate on JPEG (Wallace, 1991) and JPEG2000 (Skodras et al., 2001) compression schemes and their related transformations (namely, Discrete Cosine Transform and Discrete Wavelet Transform). We feel that common image compression standards such as JPEG and JPEG2000 have the highest potential for actual usage in real life, since the image will always have to decompressed and presented to a human at some point. From that perspective it seems reasonable to use a well-known and commonly implemented compression format that any device can decompress.
The rest of this chapter comprises of four sections. In section 2 we shall give an overview of research in spatial (pixel) domain, mainly focusing on the influence that degraded image quality (due to compression) has on recognition accuracy. In section 3 we shall follow the same lines of thought for the transform (compressed) domain research, also covering some research that is well connected to the topic even though the actual experiments in the surveyed papers were not performed with face recognition scenarios. We feel that the presented results from other research areas will give potential future research directions. In section 4 we review the presented material and try to pinpoint some future research directions.

2. Spatial (pixel) domain

In this section, we shall give an overview of research in spatial (pixel) domain, mainly focusing on the influence that degraded image quality (due to compression) has on recognition accuracy. As depicted in Fig. 1, the compressed data is usually stored in a database or is at the output of some imaging equipment. The data must go through entropy decoding, inverse quantization and inverse transformation (IDCT in JPEG or IDWT in JPEG2000) before it can be regarded as an image. Such a resulting decompressed image is inevitably degraded, due to information discarding during compression. Point A thus represents image pixels and we say that any recognition algorithm using this information works in spatial or pixel domain. Any recognition algorithm using information at points B, C or D is said to be working in compressed domain and is using transform coefficients rather than pixels at its input. The topic of papers surveyed in this section is the influence that this degradation of image quality has on face recognition accuracy (point A in Fig. 1). The section is divided into two subsections, one describing JPEG-related work and one describing JPEG2000-related work. At the end of the section we give a joint analysis.

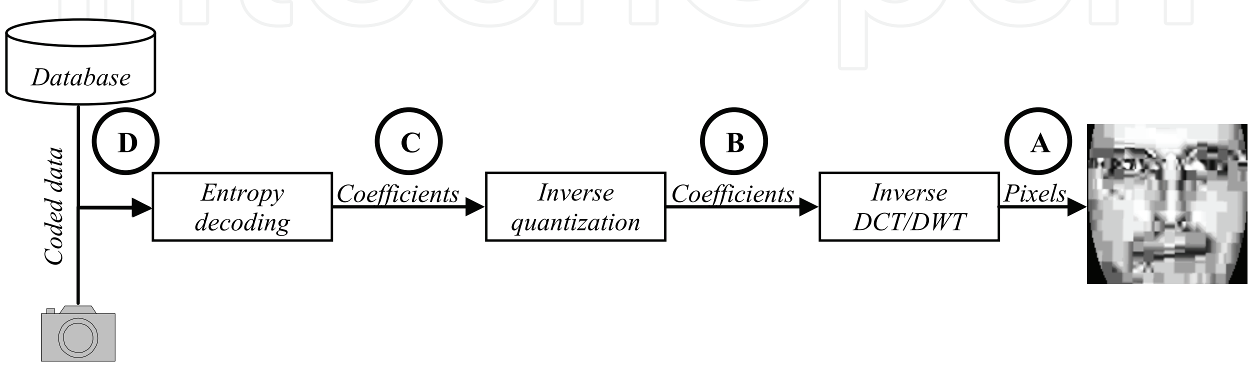

Fig. 1. Block diagram of decompression procedure in transform coding scenario

2.1 JPEG

In their FRVT 2000 Evaluation Report, Blackburn et al. tried to evaluate the effects of JPEG compression on face recognition (Blackburn et al., 2001). They simulated a hypothetical real-life scenario: images of persons known to the system (the gallery) were taken in near-ideal conditions and were uncompressed; unknown images (the probe set) were taken in uncontrolled conditions and were compressed at a certain compression level. Prior to experimenting, the compressed images were uncompressed (thus, returning to pixel domain), introducing compression artifacts that degrade image quality. They used standard galley set (*fa*) and probe set (*dup1*) of the FERET database for their experiments. The images were compressed to 0.8, 0.4, 0.25 and 0.2 bpp. The authors conclude that compression does not affect face recognition accuracy significantly. More significant performance drops were noted only under 0.2 bpp. The authors claim that there is a slight increase of accuracy at some compression ratios and that they recommend further exploration of the effects that compression has on face recognition.

Moon and Phillips evaluate the effects of JPEG and wavelet-based compression on face recognition (Moon & Phillips, 2001). The wavelet-based compression used is only marginally related to JPEG2000. Images used as probes and as gallery in the experiment were compressed to 0.5 bpp, decompressed and then geometrically normalized. System was trained on uncompressed (original) images. Recognition method used was PCA with L1 as a nearest neighbor metric. Since they use FERET database, again standard gallery set (*fa*) was used against two also standard probe sets (*fb* and *dup1*). They noticed no performance drop for JPEG compression, and a slight improvement of results for wavelet-based compression.

Wat and Srinivasan (Wat & Srinivasan, 2004) explored the effects of JPEG compression on PCA and LDA with the same setup as in (Blackburn et al., 2001) (FERET database, compressed probes, uncompressed gallery). Results were presented as a function of JPEG quality factor and are therefore very hard to interpret (the same quality factor will result in a different compression ratios for different images, dependent on the given image's statistical properties). By using two different histogram equalization techniques as a preprocessing, they claim that there is a slight increase in performance with the increase in compression ratio for LDA in the illumination task (*fc* probe set). For all other combinations, the results remain the same or decrease with higher compressions. This is in slight contradiction with results obtained in (Blackburn et al., 2001).

2.2 JPEG2000

JPEG2000 compression effects were tested by McGarry et al. (McGarry et al., 2004) as part of the development of the ANSI INCITS 385-2004 standard: "Face Recognition Format for Data Interchange" (ANSI, 2004), later to become the ISO/IEC IS 19794-5 standard: "Biometric Data Interchange Formats - Part 5: Face Image Data" (ISO, 2004). The experiment included compression at a compression rate of 10:1, later to become an actual recommendation in (ANSI, 2004) and (ISO, 2004). A commercial face recognition system was used for testing a vendor database. There are no details on the exact face recognition method used in the tested system and no details on a database used in experiments. In a similar setup as in previously described papers, it was determined that there is no significant performance drop when using compressed probe images. Based on their findings, the authors conjecture that compression rates higher than 10:1 could also be used, but they recommend a 10:1 compression as something that will certainly not deteriorate recognition results.

Wijaya and Savvides (Wijaya & Savvides, 2005) performed face verification on images compressed to 0.5 bpp by standard JPEG2000 and showed that high recognition rates can be achieved using correlation filters. They used CMU PIE database and performed two experiments to test illumination tolerance of the MACE filters-based classifier when JPEG2000 decompressed images are used as input. Their conclusion was also that compression does not adversely affect performance.

Delac et al. (Delac et al., 2005) performed the first detailed comparative analysis of the effects of standard JPEG and JPEG2000 image compression on face recognition. The authors tested compression effects on a wide range of subspace algorithm - metric combinations (PCA, LDA and ICA with L1, L2 and COS metrics). Similar to other studies, it was also concluded that compression does not affect performance significantly. The conclusions were supported by McNemar's hypothesis test as a means for measuring statistical significance of the observed results. As in almost all the other papers mentioned so far some performance improvements were noted, but none of them were statistically significant.

The next study by the same authors (Delac et al., 2007a) analyzed the effects that standard image compression methods (JPEG and JPEG2000) have on three well-known subspace appearance-based face recognition algorithms: PCA, LDA and ICA. McNemar's hypothesis test was used when comparing recognition accuracy in order to determine if the observed outcomes of the experiments are statistically important or a matter of chance. Image database chosen for the experiments was the grayscale portion of the FERET database along with accompanying protocol for face identification, including standard image gallery and probe sets. Image compression was performed using standard JPEG and JPEG2000 coder implementations and all experiments were done in pixel domain (i.e. the images are compressed to a certain number of bits per pixel and then uncompressed prior to use in recognition experiments). The recognition system's overall setup that was used in experiments was twofold. In the first part, only probe images were compressed and training and gallery images were uncompressed. This setup mimics the expected first step in implementing compression in real-life face recognition applications: an image captured by a surveillance camera is probed to an existing high-quality gallery image.

In the second part, a leap towards justifying fully compressed domain face recognition is taken by using compressed images in both training and testing stage. In conclusion, it was shown, contrary to common opinion, not only that compression does not deteriorate performance but also that it even improves it slightly in some cases (Fig. 2).

2.3 Analysis

The first thing that can be concluded from the papers reviewed in the above text is that all the authors agree that compression does not deteriorate recognition accuracy, even up to about 0.2 bpp. Some papers even report a slight increase in performance at some compression ratios, indicating that compression could help to discriminate persons in spite of the inevitable image quality degradation.

There are three main experimental setups used in surveyed papers:

1. training set is uncompressed; gallery and probe sets are compressed;
2. training and gallery sets are uncompressed; probe sets are compressed;
3. all images used in experiment are compressed;

Each of these setups mimics some expected real life scenarios, but most of the experiments done in research so far are performed using setup 2. Rarely are different setups compared in

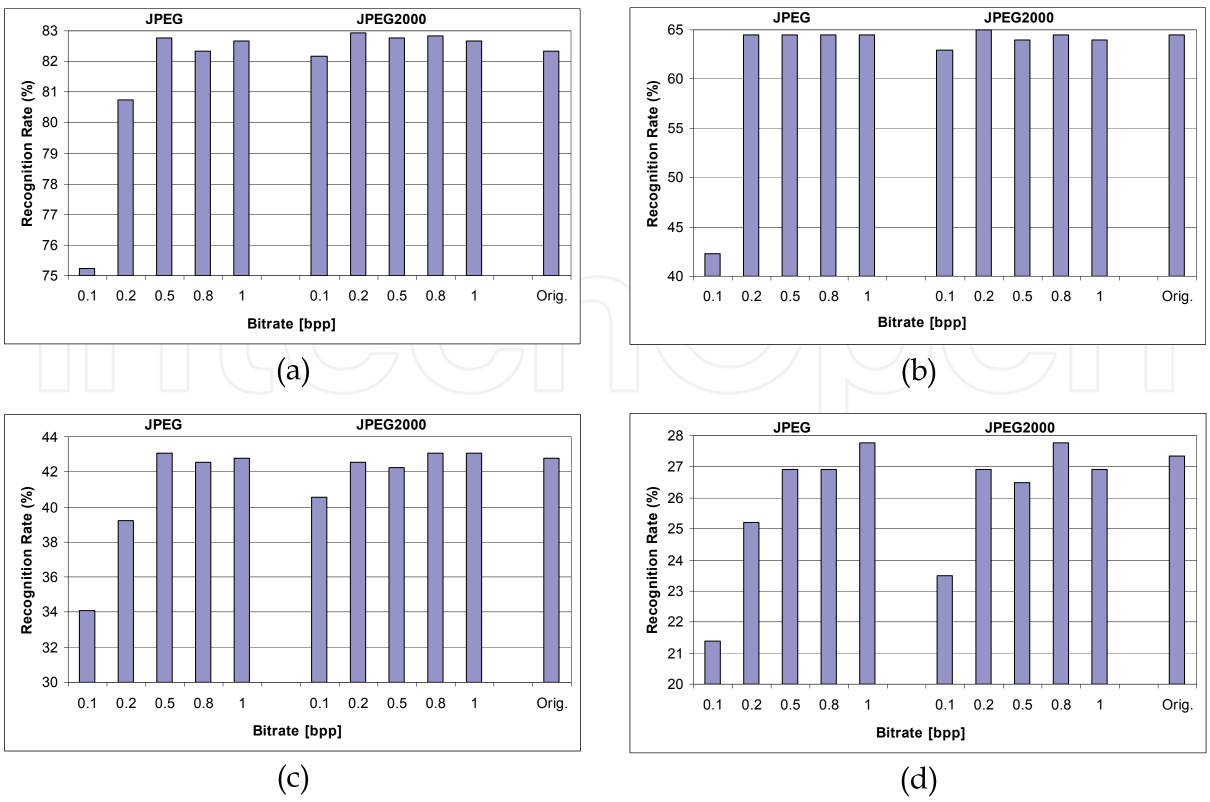

Fig. 2. ICA+COS performance as a function of bpp: (a) *fb* probe set, (b) *fc* probe set, (c) *dup1* probe set, (d) *dup2* probe set from (Delac et al., 2005)

a single paper. All the papers give the results in a form of a table or some sort of a curve that is a function of compression ratio, using an identification scenario. Verification tests with ROC graphs are yet to be done (it would be interesting to see a family of ROC curves as a function of compression ratios).

As far as the algorithms used for classification (recognition) go, most of the studies use well-known subspace methods, such as PCA, LDA or ICA. More classification algorithms should be tested to further support the claim that it is safe to use compression in face recognition. Again, with the exception of (Delac et al., 2007a), there are no studies that would compare JPEG and JPEG2000 effects in the same experimental setup. JPEG2000 studies are scarce and we believe that possibilities of using JPEG2000 in a face recognition system should be further explored.

3. Transform (compressed) domain

Before going to individual paper analysis in this section, we would like to introduce some terminology needed to understand the rest of the text. Any information that is extracted from completely compressed data (all the steps in transform coding process were done) is considered to reside in a fully compressed domain (Seales et al., 1998). Thus, fully compressed domain would be the point D in Fig. 1. Papers that we shall review here deal with the semi-compressed domain of simply compressed domain, meaning that some of the steps in decompression procedure were skipped and the available data (most often the transformed coefficients) were used for classification (face recognition in our case). Looking

at Fig. 1, we can say that those are points B and C in the decompression chain, and this is exactly what most of the papers described here use.
An important issue that comes to mind when thinking about face recognition algorithms that would operate in compressed domain is the face detection. We shall here just say that face detection in compressed domain is possible and that some work has been done on this. An interested reader can refer to (Lou & Eleftheriadis, 2000; Fonseca & Nesvadha, 2004) for a good example of research done in this area.

3.1 JPEG (DCT coefficients)

One of the first works done on face recognition in compressed domain was done by Shneier and Abdel-Mottaleb (Shneier & Abdel-Mottaleb, 1996). In their work, the authors used binary keys of various lengths, calculated from DCT coefficients within the JPEG compression scheme. Standard JPEG compression procedure was used, but exact compression rate was not given. Thus, there is no analysis on how compression affects the results. Experimental setup included entropy decoding before coefficients were analyzed. Even though the paper is foremost on image retrieval, it is an important study since authors use face recognition to illustrate their point. Unfortunately, there is little information on the exact face recognition method used and no information on face image database.
Seales et al. (Seales et al., 1998) gave a very important contribution to the subject. In the first part of the paper, they give a detailed overview of PCA and JPEG compression procedure and propose a way to combine those two into a unique recognition system working in compressed domain. Then they provide an interesting mathematical link between Euclidean distance (i.e. similarity - the smaller the distance in feature space, the higher the similarity in the original space) in feature space derived from uncompressed images, feature space derived from compressed images and correlation of images in original (pixel) space. Next, they explore how quantization changes the resulting (PCA) feature space and they present their recognition results (the achieved recognition rate) graphically as a function of JPEG quality factor and the number of eigenvectors used to form the feature space. The system was retrained for each quality factor used. In their analysis at the end of the papers, the authors argue that loading and partly decompressing the compressed images (i.e. working in compressed domain) is still faster than just loading the uncompressed image. The recognition rate is significantly deteriorated only when just a handful of eigenvectors are used and at very low quality factors.
Eickeler et al. (Eickeler e al., 1999; Eickeler et al., 2000) used DCT coefficients as input to Hidden Markov Models (HMM) for classification. Compressed image is entropy decoded and inversely quantized before features are extracted from the coefficients. Fifteen DCT coefficients are taken from each 8×8 block in a zigzag manner ($u + v \leq 4$; $u, v = 0, 1, \dots, 7$) and those coefficients are rearranged in a 15×1 feature vector. Thus, the features (extracted from one image) used as input to HMM classification make a $15 \times n$ matrix, where n is the total number of 8×8 blocks in an image. The system is tested on a database of images of 40 persons and results are shown as a function of compression ratio (Fig. 3). Recognition rates are practically constant up to compression ratio of 7.5 : 1 (1.07 bpp). At certain compression ratios, authors report a 5.5 % increase in recognition ratio compared to results obtained in the same experiment with uncompressed images. Recognition rate drops significantly only after compression ratio of 12.5 : 1 (0.64 bpp).

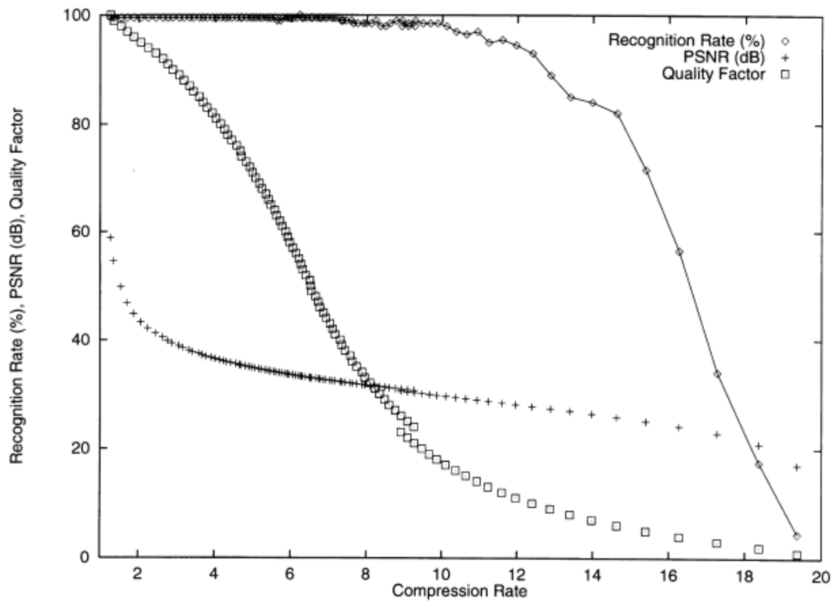

Fig. 3. A plot of recognition ratio vs. compression ratio from Eickeler et al. experiments (Eickeler et al., 2000)

Hafed and Levine (Hafed & Levine, 2001) performed related research using DCT, but they did not follow standard JPEG compression scheme. Instead, they performed DCT over the whole image and kept top 49 coefficients to be used in a standard PCA recognition scenario. The principle on which they choose those 49 coefficients is not given. In their experiment, compared to using uncompressed images, they report a 7 % increase in recognition rate. The experiment was performed on a few small databases and the results are given in tables for rank 1 and in form of a CMS curves for higher ranks.

Ngo et al. (Ngo et al., 2001) performed another related study, originally concerned with image indexing rather than face recognition. The authors took the first 10 DCT coefficients (in a zigzag order) of each 8 × 8 block and based on those 10 DCT coefficients they calculate different statistical measures (e.g. color histograms). Actual indexing is performed using covariance matrices and Mahalanobis distance. With their approach, they achieved an increase in computational speed of over 40 times compared to standard image indexing techniques. At the end of their paper the authors also report how they increased texture classification results by describing textures with variance of the first 9 AC DCT coefficients.

Inspired by human visual system, Ramasubramanian et al. (Ramasubramanian et al., 2001) joined DCT and PCA into a face recognition system based on the transformation of the whole image (since there is no division of the image into blocks, there is no real relation to JPEG). In the first experiment, all available coefficients were used as input to PCA and the yielded recognition rate was used as a benchmark in the following experiments. In the following experiments, they reduce the number of coefficients (starting with higher frequency coefficients). Analyzing the overall results, they conclude that recognition rates increase with the number of available coefficients used as input to PCA. This trend continues up to 30 coefficients. When using more than 30 coefficients the trend of recognition rate increase stops. They use their own small database of 500 images.

Tjahyadi et al. (Tjahyadi et al., 2004) perform DCT on 8 × 8 blocks and then calculate energy histograms over the yielded coefficients. They form several different feature vectors based on those histograms and calculate Euclidean distance between them as a means of classifying images. They test their system on a small database (15 persons, 165 images) and get an average recognition rate increase of 10 % compared to standard PCA method. In their conclusion, they propose combining their energy histogram-based features with some standard classification method, such as PCA, LDA or ICA. They argue that such a complex system should further increase recognition rate.

Chen et al. (Chen et al., 2005) gave a mathematical proof that orthonormal transformation (like DCT) of original data does not change the projection in PCA and LDA subspace. Face recognition system presented in this paper divides the image in 8 × 8 blocks and performs standard DCT and quantization on each block. Next, feature vectors are formed by rearranging all the coefficients in a zigzag manner. By using the FERET database and standard accompanying test sets, they showed that recognition rates of PCA and LDA are the same with uncompressed images and in compressed domain. Results remain the same even when only 20 (of the available 64) low frequency coefficients for each block are used as features. Fig. 4 shows the results of their experiments for PCA with *fc* and *dup2* probe sets.

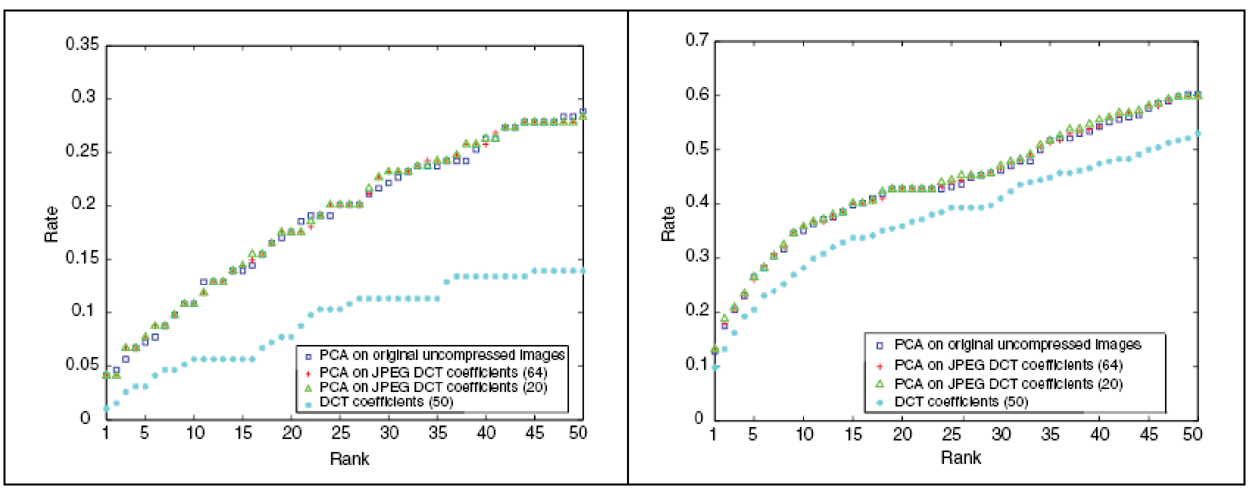

Fig. 4. Performance of PCA in JPEG DCT domain with 20 coefficients and 64 coefficients of each block for the *fc* (left) and *dup2* (right), from (Chen et al., 2005)

They concluded that significant computation time savings could be achieved by working in compressed JPEG domain. These savings can be achieved in two ways: i) by avoiding inverse transformation (IDCT) and ii) by using only a subset of all available coefficients (20 per each 8 × 8 block in this case). Another obvious consequence of their experiments is the fact that storage requirements also drop considerably.

The works presented in (Jianke et al., 2003; Pan et al., 2000) are another example of face recognition in compressed domain, but they are very similar to all the papers already presented in this section. Valuable lessons can be learned from content-based image retrieval (CBIR) research and some good examples from that area can be found in (Lay & Ling, 1999; Jiang et al., 2002; Climer & Bahtia, 2002; Feng & Jiang, 2002; Wu & Liu, 2005; Zhong & Defée, 2004; Zhong & Defée, 2005).

3.2 JPEG2000 (DWT coefficients)

First of all, we would like to point an interested reader to an excellent overview of pattern recognition in wavelet domain that can be found in (Brooks et al., 2001). It would also be worthwhile to mention at this point that most the papers to be presented in this section does not deal with JPEG2000 compressed domain and face recognition in it. They mostly deal with using wavelets as part of the face recognition system, but without any compression or coefficient discarding. They were chose however to be presented here because we believe they form a strong starting point for any work to be done in JPEG2000 domain in future. The work presented in (Delac et al., 2007b) is along those lines of thought.

Sabharwal and Curtis (Sabharwal & Curtis, 1997) use Daubechies 2 wavelet filter coefficients as input into PCA. The experiments are performed on a small number of images and the number wavelet decomposition was increased in each experiment (up to three decompositions). Even though the authors claim that the images were compressed, it remains unclear exactly what they mean since no discarding of the coefficients, quantization or entropy coding was mentioned. The recognition rates obtained by using wavelet coefficients (regardless of the number of decompositions) were in most cases superior to the results obtained with uncompressed images. The observed recognition rate increases were mostly around 2 %. Surprisingly, recognition rates were increasing with the increase of the number of decompositions.

Garcia et al. (Garcia et al., 2000) performed one standard wavelet decomposition on each image from the FERET database. This gave four bands, each of which was decomposed further (not only the approximation band). This way there are 15 detail bands and one approximation. No details on the exact wavelet used were reported. Mean values and variances were calculated for each of the 16 bands and feature vector is formed from those statistical measures. Battacharyya distance was used for classification. The authors did not use standard FERET test sets. They compare their results with the ones obtained using uncompressed (original) images and standard PCA method. The overall conclusion that was given is that face can be efficiently described with wavelets and that recognition rates are superior to standard PCA method with original images.

Similar idea can be found in (Feng e al., 2000) as well. However, in this paper several wavelets were tested (Daubechies, Spline, Lemarie) to finally choose Daubechies 4 to be used in a PCA-based face recognition system. The HH subband after three decompositions was used as input to PCA and recognition rate increase of ≈ 5% was reported.

Xiong and Huang (Xiong & Huang, 2002) performed one of the first explorations of using features directly in the JPEG2000 domain. In their work, they calculate first and second moment of the compressed images and use those as features for content-based image retrieval. Even though this paper does not strictly relate to face recognition, it represents an important step towards fully compressed domain pattern recognition. Authors recognize avoiding IDWT as one of the most important advantages of their approach. In their experiments, the authors used images compressed to 4 bpp (20:1). They observed only a small retrieval success drop on those images and recommend further research of various possible feature extraction techniques in the compressed domain.

Chien and Wu (Chien & Wu, 2002) used two wavelet decompositions to calculate the approximation band, later to be used in face recognition. Their method performed slightly better than standard PCA. Similarly, in (Li & Liu, 2002) Li and Liu showed that using all the DWT coefficients after decomposition as input to PCA yields superior recognition rates compared to standard PCA.

Two decompositions with Daubechies 8 wavelet were used by Zhang et al. (Zhang et al., 2004) with the resulting approximation band being used as input into a neural network-based classifier. By experimenting with several databases (including FERET) significant recognition rates improvements were observed compared to standard PCA in all experiments. Unfortunately, standard FERET test sets were not used so it is hard do compare the results with other studies.

Algs.	**DWT coefficients (JPEG2000 at 1 bpp)**				**DWT coefficients (JPEG2000 at 0.5 bpp)**			
	fb	*fc*	*dup1*	*dup2*	*fb*	*fc*	*dup1*	*dup2*
PCA+L1	77.8	49.0	37.1	18.8	79.0	50.0	38.2	18.4
PCA+L2	75.0	19.6	32.4	8.5	75.1	19.6	33.0	9.8
PCA+COS	73.8	19.6	33.9	10.7	73.9	18.6	33.8	10.3
LDA+L1	72.3	18.6	34.6	15.0	72.6	19.6	35.2	15.0
LDA+L2	75.6	22.2	32.7	9.0	75.7	23.2	33.0	9.8
LDA+COS	74.1	21.6	34.1	10.3	74.6	21.1	34.2	10.3
ICA+L1	65.9	18.0	32.4	22.2	65.3	13.9	31.6	21.4
ICA+L2	75.7	45.4	33.7	23.5	75.5	46.4	33.2	22.7
ICA+COS	83.0	68.0	42.9	31.6	82.8	67.5	43.5	31.6

Table 1. Results of the experiments from (Delac et al. 2007b). The numbers in the table represent rank 1 recognition rate percentages.

By using Daubechies 4 wavelet and PCA and ICA, Ekenel and Sankur (Ekenel & Sankur, 2005) tried to find the subbands that are least sensitive to changing facial expressions and illumination conditions. PCA and ICA were combined with L1, L2 and COS metrics in a standard nearest neighbor scenario. They combine images from two databases and give no detail on which images were in the training, gallery and probe sets. An important contribution of this paper lays in the fact this study is performed in a very scientifically strict manner since the same recognition method is used once with uncompressed pixels as input (what we so far referred to as standard PCA method) and once with DWT coefficients as input. In the experiment with images of different expressions, no significant difference in recognition results using uncompressed images and DWT coefficients was observed. In the experiment with images with different illumination conditions, a considerable improvement was observed when DWT coefficients were used instead of pixels (over 20% higher recognition rate for all tested methods).

In (Delac et al., 2007b) the authors showed that face recognition in compressed JPEG2000 domain is possible. We used standard JPEG2000 scheme and stopped the decompression process at point B (right before the inverse DWT). We tested three well-known face recognition methods (PCA, LDA and ICA) with three different metrics, yielding nine different method-metric combinations. FERET database was used along with its standard accompanying protocol. No significant performance drops were observed in all the experiments (see Table 1). The authors therefore concluded that face recognition algorithms can be implemented directly into the JPEG2000 compressed domain without fear of deleterious effect on recognition rate. Such an implementation would save a considerable amount of computation time (due to avoiding the inverse DWT) and storage and bandwidth requirements (due to the fact that images could be compressed). Based on our research we also concluded that JPEG2000 quantization and entropy coding eliminate DWT coefficients not essential for discrimination. Earlier studies confirm that information in low spatial frequency bands plays a dominant role in face recognition. Nastar et al. (Nastar & Ayach, 1996) have investigated the relationship between variations in facial appearance and their deformation spectrum. They found that facial expressions and small occlusions affect the intensity manifold locally. Under frequency-based representation (such as wavelet transform), only high frequency spectrum is affected. Another interesting result that needs to be emphasized is the improvement in recognition rate for PCA and LDA algorithms for the *fc* probe set. This further justifies research into possible implementation of face recognition algorithms directly into JPEG2000 compressed domain, as it could (as a bonus benefit) also improve performance for different illumination task.

3.3 Analysis

From the papers reviewed in this section, one can draw similar conclusion as in previous section: working in compressed domain does not significantly deteriorate recognition accuracy. However, it is important to mention that this claim is somewhat weaker than the one about compression effects when using decompressed images (previous section) since many of the papers surveyed here do not directly use JPEG or JPEG2000 domain. Those that do, however, still agree that working in compressed domain does not significantly deteriorate recognition accuracy. Additionally, most of the papers presented report a slight (sometimes even significant) increase in recognition rates. Although we only presented a short description of each of the papers, when analyzing them in more depth it is interesting to notice that most of them stopped the decompression process at points B or C (Fig. 1). We found no papers that would use entropy-coded information.

We already mentioned that main advantages of working in compressed domain are computational time savings. Inverse discrete cosine transform (IDCT) in JPEG and inverse discrete wavelet transform (IDWT) in JPEG2000 are computationally most intensive parts of the decompression process. Thus, any face recognition system that would avoid IDCT would theoretically save up to $O(N^2)$ operations, where N is the number of pixels in an image. If DCT is implemented using FFT, the savings would be up to $O(N\log N)$. Theoretical savings by avoiding IDWT are up to $O(N)$.

Looking at the papers presented here and analyzing what was done so far, we can conclude that this area is still quite unexplored. There are currently only a handful of papers that deal with JPEG compressed domain and just one paper that deals with face recognition in JPEG2000 domain (Delac et al., 2007b). Additional encouragement to researchers to further explore this area can be found in the success of compressed domain algorithms in other areas, most obviously in CBIR (Mandal et al., 1999).

4. Conclusions

In this chapter we have presented an extensive literature survey on the subject of image compression applications in face recognition systems. We have categorized two separate problems: i) image compression effects on face recognition accuracy and ii) possibilities of performing face recognition in compressed domain. While there are a couple of papers dealing with the former problem strictly connected to JPEG and JPEG2000 compression, the latter problem is up to now only superficially researched. The overall conclusion that can be drawn from research done so far is that compression does not significantly deteriorate face recognition accuracy, neither in spatial domain nor in compressed domain. In fact, most of the studies show just the opposite: compression helps the discrimination process and increases (sometimes only slightly, sometimes significantly) recognition accuracy.

We have also identified a couple important issues that need to be addressed when doing research on compression in face recognition: experimental setup to mimic the expected real life scenario and the problem of results representation. For instance, quality factor in JPEG should be avoided as it will yield different compression ratios for each image, dependent on the contents on the image. There seems to be a need for a consensus on results presentation. Having in mind that the number of bits per pixel (bpp) is the only precise measure of compression, all results should be presented as a function of bpp and compared to results from pixel domain in the same experimental setup.
There is still a lot of work to be done but given that face recognition is slowly entering our everyday lives and bearing in mind the obvious advantages that compression has (reducing storage requirements and increasing computation speed when working in compressed domain), further research of this area seems inevitable.

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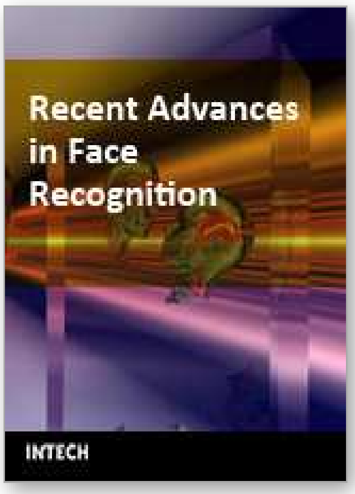

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