Compression of Touchless Multiview Fingerprints

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***Abstract*—Recently, touchless multiview fingerprinting technology has been proposed as an alternative to overcome the intrinsic problems of traditional contact-based systems. Nevertheless, compression of this kind of signal has not been fully evaluated and standardized. This paper investigates the comparative performance of several encoders for this data, namely WSQ, JPEG2000, H.264/AVC and MMP. Experimental results show that WSQ encoder, which is the current compression standard for contact-based fingerprints, is objectively outperformed by all others. In particular, MMP, which achieved the best results, outperforms WSQ by up to 4 dB.**

***Index Terms*—Biometrics, fingerprint recognition, touchless, multiview, image coding.**

I. Introduction

Biometric authentication, or simply biometrics, may be defined as the automatic verification or identity recognition of an individual based on physiological and behavioral characteristics [1]. Fingerprint, hand geometry, voice, iris, face, handwrite and keystroke are examples of such characteristics. In general, different biometric systems require specific technologies, depending on the physiological/behavioral characteristic being used. However, despite of the specificity of each biometric system, there are some problems that must be addressed by most of them. Storage and transmission [2] of collected samples is one of these problems, especially when samples are meant to be processed by a remote computer. In this case, data compression techniques are required.

A. Contact-based Fingerprints

It is not obvious to determine which single physiological/behavioral characteristic is the most appropriate for all possible applications and operation conditions. Nevertheless, in forensic, civil and commercial applications [3], fingerprints have become widely used. The input of fingerprint authentication systems are digital images representing the ridge-valley structure of real fingers. This means that the image acquisition process is a critical step, that drastically affects the overall performance of the system. Most of today's fingerprinting technology is contact-based, demanding the user to press a finger against a scanning surface. Major problems with this technology are the uncontrollable distortions and inconsistencies that may be introduced due to skin elasticity. Fingerprint quality may also be seriously influenced by nonideal contact caused by dirt, sweat, moisture, excessive dryness, air humidity, temperature and latent fingerprints. Furthermore, different parts of the same finger may be captured each time it is presented to the sensor, leading to irreproducible samples. In some scenarios, the above-mentioned drawbacks [4] impose the need of a highly trained operator and often require several attempts per finger, in order to ensure a successful nail-to-nail enrollment. Government applications, for instance, which demand the population's registration, may become very time-consuming. Although over the past few years many algorithms have been proposed to compensate the limitations of contact-based technology, this sensing paradigm may represent a bottleneck for further improvement of fingerprint image quality.

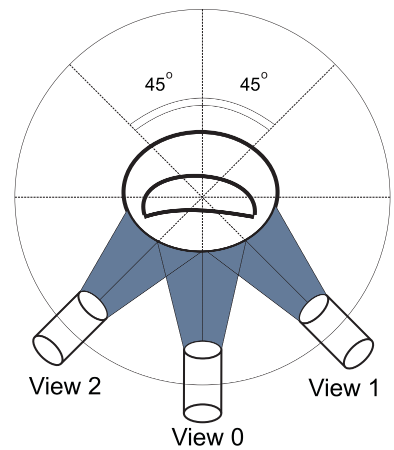

Fig. 1: Schematic illustration of a touchless multiview fingerprint device.

B. Touchless Fingerprinting Technologies

Recently, contactless (or touchless) fingerprinting solutions has been proposed [5], [6], [7] as an effort to overcome the intrinsic problems of contact-based systems. The breakthrough is that the contactless concept attacks the sample quality problem at its fundamental level. Since contactless devices do not compel users to press their fingers on a platen, they do not depend on algorithms that try to compensate artifacts caused by skin elasticity or latent fingerprints.

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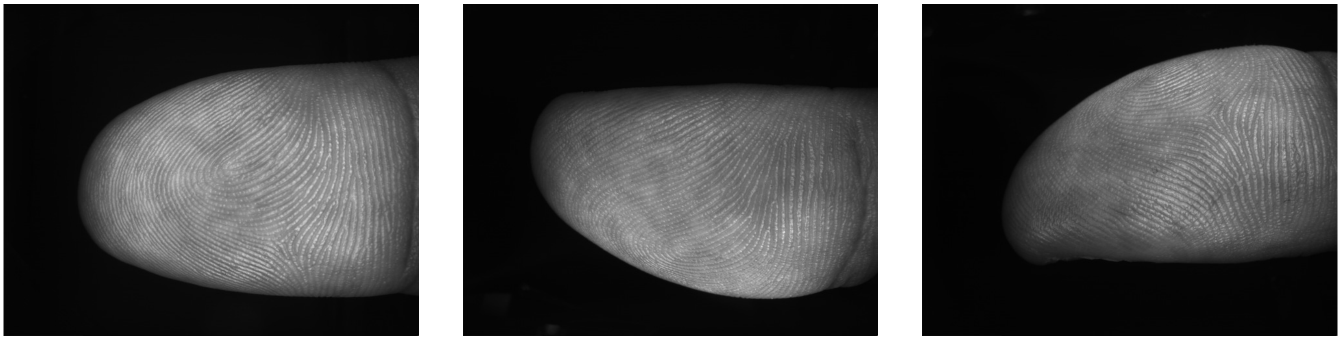


(a) View 0 (b) View 1 (c) View 2

Fig. 2: Example of fingerprint views (1024×1280 pixels, 8 bits/pixels) acquired by a touchless 3-camera fingerprint device.

Among the proposed touchless solutions, TBS's[1] devices [8] use an interesting and very promising approach. These devices combine reflection-based touchless finger imaging with a three-camera multiview system. One camera is positioned to capture the portion of the finger where normally the core and the delta are located, and taking this central camera as a reference, the other two are displaced by around 45 degrees clockwise and counter-clockwise. If the overlapping of their fields of view is guaranteed, as depicted in Figure 1, one may not only increase the captured area, but also enable the construction of a rolled-equivalent (nail-to-nail) fingerprint by using image stitching algorithms [9]. Figures 1 and 2 show a schematic illustration of a multi-camera touchless device and an example of captured views, respectively.

Another successful technology that addresses the limitations of contact-based scanners is presented by FlashScan3D[2] [10]. In addition to touchless data acquisition, it relies on structured light illumination (SLI) to extract texture and ridge depth information [11], enabling a 3D representation of the finger topography. Note that this solution does not use a multi-camera approach and will not be evaluated in our tests.

C. Context and Motivation

Considering a scenario where the views produced by an optical touchless multiview device must be first stored for later transmission or processing, image coding algorithms are required. Since compression of this kind of signal has not been fully evaluated and standardized, this paper proposes a comparison of the Wavelet Scalar Quantization (WSQ) image coder [12], which is the actual fingerprint compression standard for contact-based images, with three other coders: JPEG2000 [13], H.264/AVC [14] and Multidimensional Multiscale Parser (MMP) [15].

In this work we do not evaluate the recognition accuracy after compression. Nevertheless, since touchless technology outputs grayscale photographic images with superior quality, biometric systems based on this kind of signal may be more robust and distinctive [1].

[1] http://www.tbsinc.com/

[2] http://www.flashscan3d.com/

II. Fingerprint Image Coders

WSQ is the current standard for compression of contact-based fingerprints images, proposed by the Federal Bureau of Investigation (FBI). However, images produced by a touchless multiview system present different characteristics when compared to those captured by an optical contact-based device, as show in Figure 3. Furthermore, in this new context one must deal with three images per sample, rather than one, and therefore WSQ may not be the most appropriate approach. In the next subsections we will briefly present the image coders used in our tests.

A. WSQ

The WSQ is a lossy compression algorithm that consists of three main stages: (i) discrete wavelet transform decomposition of the input image, (ii) scalar quantization of the transform coefficients and (iii) entropy coding based on run-length coding of zeros and Huffman coding. It has become a standard for the exchange and storage of contact-based fingerprint images. Although WSQ is a format with a large degree of flexibility, several parameters are fixed for the purpose of fingerprint image compression. The WSQ wavelet is a biorthogonal wavelet Cohen-Daubechies-Feauveu (CDF) 9-7, with a complex decomposition in 64 subbands.

Two main reasons led to the widespread use of WSQ standard. One is the absence of blocking artifacts (due to the use of a wavelet decomposition instead of block-based discrete cosine transform). The other one is the preservation of certain minutiae features even at high compression ratios.

B. JPEG2000

Also based on wavelet transforms, the JPEG2000 is a lossy and lossless image coding standard. For lossy compression it also uses the CDF 9-7 transform, while for lossless compression it uses the CDF 5-3 transform. For subband decomposition, JPEG2000 uses the simple Mallat structure. After the transformation, the wavelet coefficients are quantized using a scalar dead-zone quantization and an arithmetic entropy coder is applied, namely the binary MQ-coder.

(a) (b)

Fig. 3: Comparisson between: (a) contact-based and (b) touchless fingerprints (View 0).

Some previous results have shown that JPEG2000 provides better compression than the WSQ, for contact-based images, with less impact on the overall accuracy performance of a biometric system [16].

C. H.264/AVC

H.264/AVC is a video compression standard and it was not at first conceived to be used as a still image compression tool. Nevertheless, the many coding advances brought into H.264/AVC, not only set a new benchmark for video compression, but they also made it a very efficient compressor for still images [17]. We refer to this coder as AVC-I. Gains of the AVC-I over JPEG2000 are typically in the order of 0.25 to 0.5 dB in PSNR for pictorial grayscale images. AVC-I is a block-based algorithm using a discrete cosine transform, but it incorporates a deblocking loop filter, that can minimize undesired blocking artifacts.

More recently, H.264/AVC has also been successfully used as a framework for a hybrid pattern matching/transform-based compression engine applied to scanned books [18]. This method, referred to as advanced document coding (ADC), uses segments of the originally independent scanned pages of a document to create a video sequence, which is further encoded through regular H.264/AVC. Natural text patterns along a document typically presents repetitive symbols such that dictionary-based compression methods become very efficient. For document coding, results show that ADC objectively outperforms AVC-I and JPEG2000 by up to 4 dB and 7 dB, respectively. Furthermore, the encoder outputs documents with superior subjective quality.

D. MMP

The Multidimensional Multiscale Parser algorithm (MMP), was originally proposed as a generic lossy pattern matching data compression method [19], and has been successfully used for lossy and lossless compression of several types of data sources. It can be seen as a combination of the Lempel-Ziv methods (LZ) and vector quantization (VQ), as input data segments of variable dimensions are approximated using codevectors stored in an adaptive dictionary, updated with previously compressed patterns. Furthermore, its high versatility results from a feature that distinguishes it from the previous algorithms: the use of scale adaptive pattern matching.

Every new pattern generated by the concatenation of two previously encoded adjacent vectors will be available to approximate vectors of any dimensions, through the use of scale transformations. These features result in an high degree of adaptivity, that supports state-of-the-art R-D performances for a wide range of applications [15].

As MMP, similarly to H.264/AVC-I, is a block based encoder, it also suffers from blocking artifacts, specially at low-to-medium bitrates. Therefore, we have adopted an adaptive deblocking filter to minimize the blocking artifacts, without the need of sending any side information [15]. The activity of each block is determined in order to locally set the shape and support of the adaptive filter. Highly detailed areas use narrower filters, while smooth areas use filters with large support regions. Filtering has shown gains up to 0.3dB in the reconstruction, without any noticeable degradation of detail.

III. Experimental Results

In our experiments, 6 different test samples (18 views) are compressed using WSQ, JPEG2000, AVC-I, ADC and MMP. In WSQ, JPEG2000, and AVC-I, the views are independently encoded. For ADC, each view is segmented into $Np = 16$ frames and the 48 resulting frames are used to build a video sequence. The first frame is encoded as an I-frame (only intraframe prediction modes are used) and all the remaining frames are encoded as P-frames (intra and inter prediction modes are used). The number of reference frames is 16 and the search range is 128.

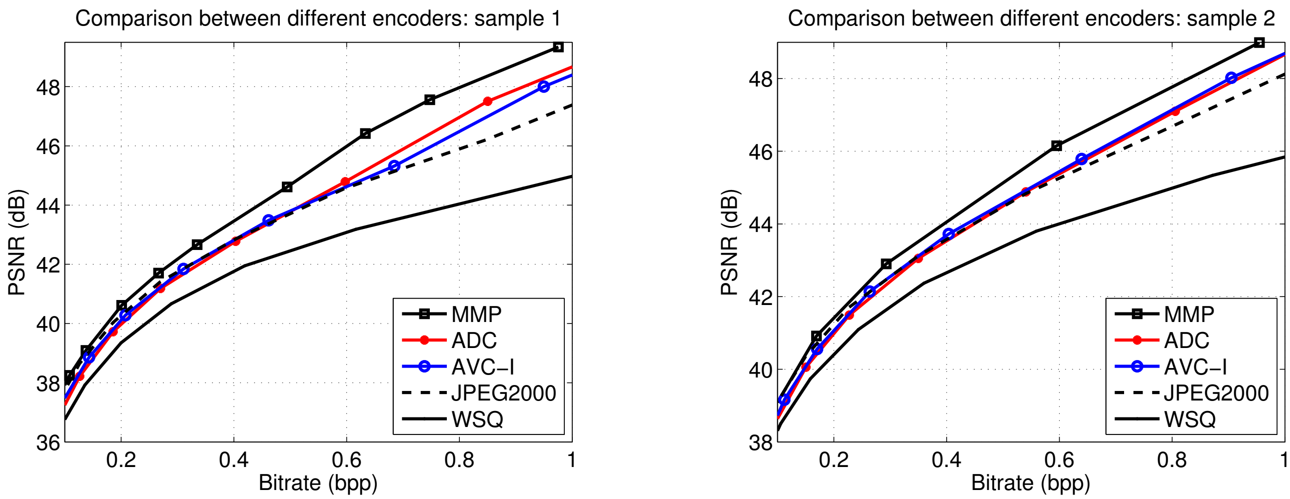
Regarding the MMP encoder, several setups were investigated. Experimental tests showed that best results were obtained with the use of a predictive scheme. Additionally, as similar patterns tend to occur in the different views of the same sample, the three views are compressed sequentially using a common adaptive codebook. For this purpose, the three views are concatenated into one single image with 3 times the height of the views and the original width. This preserves the codewords generated in the compression of each view, increasing the dictionary's approximation power and the R-D performance of the method.

Figures 4 (a) and (b) show PSNR plots for samples 1 and 2. Table I show comparative results also for samples 3 to 6. The PSNR was calculated using the joint mean square error (MSE) of the views.

IV. Conclusions

In this paper we highlight the fact that no encoding standard has yet been proposed for touchless multiview fingerprint images and investigate the rate-distortion performance of state-of-the-art encoders for 6 samples.

We conclude that WSQ, which is the present compression standard for contact-based fingerprints, is outperformed by all others. Moreover, AVC-I and ADC present better performance



(a) sample 1

(b) sample 2

Fig. 4: PSNR plots for samples 1 and 2: WSQ is outperformed by all other tested encoders. MMP presents the best results. In particular, it outperforms WSQ by up to 4 dB.

TABLE I: Comparative results [dB].

	Rate	0.10bpp	0.30bpp	0.50bpp	0.70bpp
Sample 3	MMP	**40.51**	**44.08**	**46.84**	**48.48**
	ADC	40.04	43.09	46.09	48.09
	AVC-I	40.29	44.00	46.09	47.99
	JPEG2000	40.30	43.82	45.69	47.22
	WSQ	39.37	42.77	44.28	45.26
Sample 4	MMP	**42.44**	**45.38**	**47.18**	**48.71**
	ADC	41.92	44.98	46.67	48.39
	AVC-I	42.10	45.03	46.66	48.19
	JPEG2000	42.38	45.15	46.58	47.88
	WSQ	41.63	44.46	45.43	46.17
Sample 5	MMP	**39.03**	**42.96**	**45.11**	**47.06**
	ADC	38.60	42.43	44.55	46.31
	AVC-I	38.75	42.56	44.61	46.31
	JPEG2000	38.95	42.35	44.29	45.85
	WSQ	38.17	41.52	43.19	44.30
Sample 6	MMP	**41.16**	**44.87**	**47.13**	**49.03**
	ADC	40.77	44.44	46.49	48.38
	AVC-I	40.94	44.59	446.47	48.21
	JPEG2000	41.14	44.49	46.24	47.71
	WSQ	40.32	43.64	44.95	45.75

than JPEG2000 in the range of 0.5 to 1.0 $bits/pixel$. On the other hand, at higher compression ratios, the H.264/AVC based methods are outperformed by JPEG2000, probably because of blocking artifacts that cannot be efficiently filtered. When it comes to H.264/AVC based encoders, AVC-I presents better results than ADC at lower bitrates. The lack of good references for motion estimation limits the performance of ADC. However, this tendency is inverted at higher bitrates.

Finally, the recently proposed MMP is the most efficient algorithm for this kind of data, consistently outperforming all other tested encoders. Consistent gains up to 1.2 dB for all samples were observed. In particular, it outperforms WSQ by up to 4 dB. Superior subjective quality may also be achieved due to the use of a deblocking filter.

Regardless of the biometric characteristic being considered, automatic verification or identity recognition systems are usually designed to minimize false rejection (a true user is rejected) and false acceptance (a false user is accepted) rates. Therefore, signal processing algorithms should not introduce artifacts that could interfere with subsequent feature extraction and matching procedures. This analysis has not been carried out in this paper and will be considered in future works.

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