

# Recognition Impact of JPEG2000 Part 2 Wavelet Packet Subband Structures in IREX K3 Iris Image Compression

Jutta Hämmerle-Uhl, Ernst Tillian, and Andreas Uhl

**Abstract**—The impact of using (adaptive) wavelet packet subband structures as allowed in JPEG2000 Part 2 in iris image compression is investigated. The recognition performance of four different feature extraction schemes applied to correspondingly compressed images is compared to the usage of the dyadic decomposition structure of JPEG2000 Part 1 in the compression stage. A better recognition performance of the adaptively generated wavelet subband structures is observed, in particular of those generated with respect to optimal rate-distortion performance.

**Index Terms**—JPEG2000, wavelet packets, iris recognition, IREX.

## I. INTRODUCTION

Iris recognition [1] is one of the most deployed biometric modalities, standardized by the International Civil Aviation Organization (ICAO) for use in future passports, and one of the technologies in the Unique Identification Authority of India's (UID) Aadhaar project to uniquely identify Indian citizens. However, the increasing market saturation of biometric instead of conventional access control methods raises the need for efficient means to store such data. The International Organization for Standardization (ISO) specifies iris biometric data to be recorded and stored in (raw) image form (ISO/IEC FDIS 19794-6), rather than in extracted templates (e.g. iris-codes). On the one hand, such deployments benefit from future improvements (e.g. in feature extraction stage) which can be easily incorporated without re-enrollment of registered users. On the other hand, since biometric templates may depend on patent-registered algorithms, databases of raw images enable more interoperability and vendor neutrality [1]. These facts motivate detailed investigations and optimizations of image compression on iris biometrics in order to provide an efficient storage and rapid transmission of biometric records. Furthermore, the application of low-powered mobile sensors for image acquisition, e.g. mobile phones, raises the need for reducing the amount of transmitted data. There are two options to apply compression in iris recognition: The acquired sample data can be compressed and transferred as it has been obtained by the sensor (termed "rectilinear images"

or IREX K1 / K3, see Fig. 1), or the iris texture strip as obtained from prior segmentation and log-polar mapping (termed "polar iris image" or IREX K16, the latter now no longer being supported) may be compressed and transferred. The second option obviously trades off the higher computational cost at the sensor (segmentation + compression) for a minimisation of the transferred data amount.

The certainly most relevant standard for compressing image data relevant in biometric systems is the ISO/IEC 19794 standard on Biometric Data Interchange Formats where in the most recently published version (ISO/IEC FDIS 19794-6), only JPEG2000 is included for lossy compression. JPEG2000 has also been recommended for various application scenarios and standardised iris images (IREX records) by the NIST Iris Exchange (IREX <http://iris.nist.gov/irex/>) program. The ANSI/NIST-ITL 1-2011 standard on "Data Format for the Interchange of Fingerprint, Facial & Other Biometric Information" (former ANSI/NIST-ITL 1-2007) also supports only JPEG2000 for applications tolerating lossy compression.

In literature on compressing iris imagery, rectilinear [2], [3] as well as polar [4] iris sample data has been considered. With respect to employed compression technology, we find JPEG [2], [5], JPEG XR [6], JPEG2000 [2], [4], [7], and other general purpose compression techniques being investigated.

In biometrics, wavelet packet based image compression schemes have been applied before in the area of fingerprint recognition [8], [9] due to the high frequency nature of the ridge and valley pattern in fingerprint imagery. Eventually, similar to fingerprint images, image features important for iris template matching might reside in high or mid frequency parts of the iris texture, which could be represented better by adapted wavelet packet structures as compared to the fixed dyadic wavelet representation.

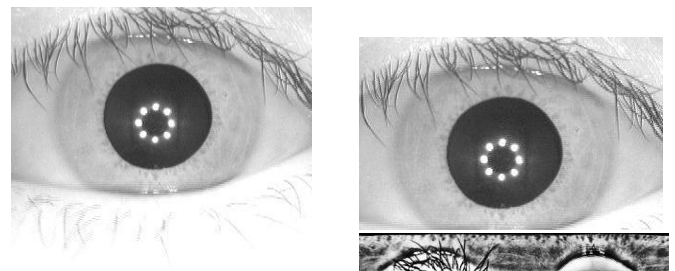


Fig. 1. IREX K1 and K3 images and extracted iris texture (K16).

In this work, we employ wavelet packet decomposition structures for the compression of IREX K1/K3 iris images using JPEG2000 Part 2 technology. Recent work [10]

Manuscript received April 23, 2014; revised June 23, 2014. This work was supported in part by the Austrian Science Fund FWF, project 15170.

J. Hämmerle-Uhl was with University of Salzburg, Austria. She is now with e-mundo Inc, Austria (e-mail: jhaemm@cosy.sbg.ac.at).

E. Tillian is with the University of Salzburg, Austria (e-mail: Ernst.Tillian@stud.sbg.ac.at).

A. Uhl is with the Computer Sciences Department, University of Salzburg, Austria (e-mail: andreas.uhl@sbg.ac.at).

showed that for polar iris image (IREX K16) common subband structure selection strategies including rate-distortion optimising ones are not very successful as compared to the dyadic decomposition scheme (defined in the Part 1 of the JPEG2000 standard suite). However, we were able to demonstrate some limited performance gain using evolutionary optimization for selecting wavelet packet subband structures [11]. In this work, we re-investigate the usage of common wavelet packet subband structure selection strategies including rate-distortion optimising ones for rectilinear K1/K3 imagery.

In Section II, we review the use of wavelet packets in JPEG2000 and discuss various wavelet packet subband structure selection strategies. Section III provides experimental results for four different iris recognition schemes while Section IV concludes the paper.

## II. WAVELET PACKET SELECTION AND JPEG2000

Optimization of compression algorithms to meet the specific properties of the data to be compressed and to tailor them to the application scenario is a natural strategy. For example, JPEG quantization matrix optimization has already been considered in biometrics – [12] employ a rate/distortion criterion in the context of face recognition while we have designed optimized JPEG matrices for iris data compression in recent work [5] (both approaches led to improved recognition results).

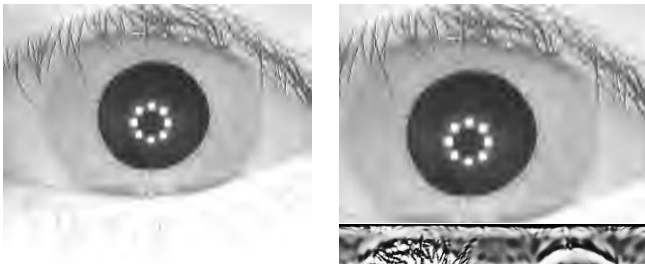


Fig. 2. Images of Fig. 1 under 0.1 bpp JPEG2000 compression.

Apart from allowing the specification of user-defined wavelet filters, JPEG2000 Part 2 also facilitates the use of more general wavelet packet subband structures [13] in the wavelet decomposition, as opposed to the fixed dyadic scheme in Part 1. However, the standard does not suggest a way to identify a suitable wavelet packet basis (*wpb*) for a given image. Due to the high number of *wpb*, exhaustive search is infeasible which has led to the development of various *wpb* selection strategies.

In order to determine a suited *wpb* for a particular image, the best-basis algorithm [14] can be used, “best” in the restricted sense of an additive cost function, and independent of target bitrate and employed coding scheme, respectively. Three cost functions employed in this work are the logarithm-of-energy-function (*logE*) and the  $l^p$ -norm-functions for  $p=1, 2$ , respectively [14]. Besides this obviously suboptimal (but fast) strategy, we use a JPEG2000 specific cost function optimising rate/distortion behaviour for a given bitrate (*RDOH* [15], [16]). The employment of rate-distortion optimization criteria for this type for *wpb* subband structure

selection has been first demonstrated for classical wavelet image coding schemes [17], but has been extended later to zero-tree based compression algorithms [18] and to JPEG2000 in recent work [15], [16]. In addition to that, the fixed *wpb* termed “WSQ” as defined by the FBI for fingerprint compression [19] is used in our experiments.

## III. EXPERIMENTS

### A. Experimental Settings

As sample data, we use the public CASIA V3 Interval database consisting of 2639 images from 391 eye classes with  $320 \times 280$  pixels and eight-bit grey value. These images are compressed down to 0.1 *bpp* at a compression rate of 80.

Experimental results with respect to JPEG2000 Part 1 & 2 compression have been generated using a custom implementation of *wpb* selection strategies based on the JJ2000 reference implementation (available at <http://www.wavelab.at/sources> [20]).

Depending on the data iris texture feature extraction is being applied to, two different scenarios can be distinguished:

- The compressed vs. compressed case, denoted as CCC, where both templates involved in matching, the one generated from the sample data and the one from the database, are derived from images compressed to the same bitrate.
- The compressed vs. uncompressed case, denoted as CUC, where the template generated from the compressed sample is matched against the database containing templates derived from uncompressed iris images.

It is crucial to assess the effects of compressing iris samples using different iris recognition schemes since it can be expected that different feature extraction strategies will react differently when being confronted with compression artifacts and reduced image quality in general.

We use custom implementations of four feature extraction techniques (for a description of our implementation of preprocessing, feature extraction, and matching see [18]). All implementations are available in USIT (University of Salzburg Iris-Toolkit at <http://www.wavelab.at/sources/>).

The first scheme has been developed by Ko *et al.* [20] and extracts spatial domain features, while the second approach has been designed by Monroe *et al.* [7] and relies on DCT-derived features computed from rotated texture patches. The third scheme has been published by Ma *et al.* [21] using a 1D dyadic wavelet transform maxima representation for small averaged stripes of the iris texture while the fourth technique is a re-implementation of the popular 1D log-Gabor MATLAB-code of Libor Masek.

The equal error rates (EERs) for these iris feature extraction / recognition techniques when applied to the original CASIA V3 Interval test data without JPEG2000 compression using the USIT CAHT-segmentation approach are 1.4% (Ma), 1.6% (Masek), 2.4% (Monro), and 10.6% (Ko), respectively.

Fig. 3 and Fig. 4 display corresponding genuine and

impostor matching score distributions for the schemes of Masek and Monro. Both show reasonably separated distributions, but also the distributions' overlap causing EERs unequal 0 are clearly visible.

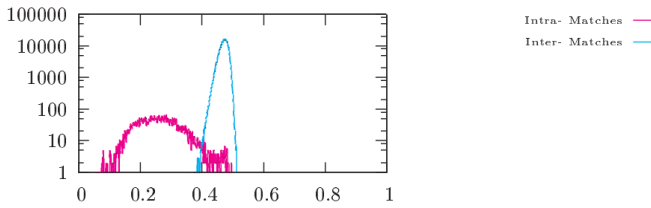


Fig. 3. Matching-score distributions for Masek (no JPEG2000 compression).

We also notice slight differences: While the Intra-class distribution in the Masek case leans towards 0 (see Fig. 3), the corresponding Monro distribution leans more towards the Inter-class distribution (see Fig. 4).

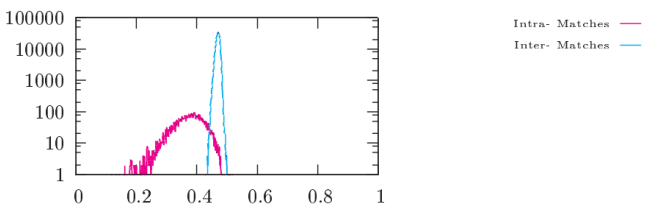


Fig. 4. Matching-score distributions (Monro - no JPEG2000 compression).

## B. Experimental Results

TABLE I: RECOGNITION ACCURACY UNDER SEVERE COMPRESSION

wpb-scheme	Feature-type	EER/CCC	EER/CUC
RDOH	Masek	10.9%	6.5%
RDOH	Ma	11.5%	8.8%
Norml1	Masek	11.7%	7.5%
Norml2	Masek	11.8%	7.5%
Dyadic	Masek	11.9%	7.5%
Dyadic	Ma	12.6%	9.8%
LogE	Masek	13.0%	8.5%
Norml1	Ma	13.1%	9.9%
Norml2	Ma	13.1%	9.9%
LogE	Ma	14.5%	11.0%
WSQ	Masek	15.9%	10.3%
WSQ	Ma	16.9%	13.1%
RDOH	Ko	17.5%	13.9%
Dyadic	Ko	18.3%	14.0%
Norml1	Ko	18.3%	14.1%
Norml2	Ko	18.3%	14.6%
LogE	Ko	19.6%	15.2%
WSQ	Ko	21.1%	17.2%
RDOH	Monro	24.0%	43.9%
Dyadic	Monro	25.3%	47.4%
Norml1	Monro	25.5%	47.6%
Norml2	Monro	25.5%	47.3%
LogE	Monro	27.1%	50.5%
WSQ	Monro	31.4%	54.6%

Table I displays the main experimental results of this work. For all four feature extraction / matching schemes considered, we present EERs under six different compression schemes (*wpb*-scheme) with a bitrate of 0.1 bpp (compression ratio 80): Two fixed decompositions (i.e. dyadic – JPEG2000 Part 1 and WSQ), three adaptive decompositions applying the

best basis algorithm (with cost functions Norml1/2 and LogE), and the rate-distortion optimizing RDOH scheme. Additionally, the two application scenarios CCC (both templates matched are derived from compressed images) and CUC (one template is computed from an uncompressed image) are compared.

The ordering displayed in the table follows the EER of the CCC scenario. We are able to identify several very clear trends. First, the CUC scenario clearly delivers consistently lower EERs, thus, if possible, it is better to only compress one of the two images involved in matching. Second, RDOH is consistently the best *wpb* selection scheme for all feature extraction schemes considered (improving over the dyadic Part 1 technique by approx. 1% EER). Third, the fixed WSQ scheme might be a good choice for fingerprints, but it is definitely not for iris imagery (it always delivers the worst result). Fourth, the cost-function based best basis techniques do hardly ever improve over the dyadic scheme, thus, they are not worth the additional computational effort.

Another issue is the general robustness of the different feature extraction / matching schemes with respect to compression. While for the original CASIA V3 Interval data, the algorithm of Ma delivers the lowest EER and that of Ko the highest one, the situation changes under the severe compression considered: The Masek scheme exhibits better robustness and delivers the best EER results under compression (in the CUC scenario even all Masek compression variants are better than each Ma variant), while the Monro scheme shows very weak compression robustness and thus results in EERs up to 50% (which means it does not deliver sensible results any more under such conditions).

Fig. 5 illustrates the impact of compression on the Masek matching score distributions.

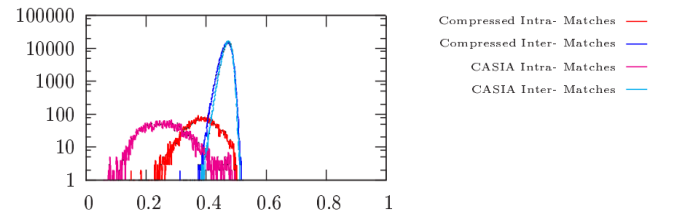


Fig. 5. Matching-score distributions for Masek under 0.1 bpp compression.

It is clearly visible that the Inter-class distribution is hardly affected by compression, while the Intra-class distribution is significantly shifted towards the Inter-class distribution causing a larger number of false negatives (false non-match rate increases), thus resulting in an increase of the overall EER. On the other hand, the distributions' overlap is still only partial, so still recognition is possible to some extent. The situation is very different for the Monro scheme as shown in Fig. 6.

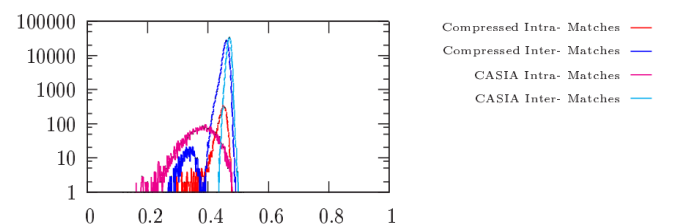


Fig. 6. Matching-score distributions for Monro under 0.1 bpp compression.

As compared to Fig. 4, Inter-class distribution is extremely broadened and exhibits a second peak around 0.3. On the other hand, Intra-class distribution is narrowed and shifted to the right, now having a peak close to 0.4. Under these circumstances it is evident, that the Monro scheme cannot be able to provide any sensible recognition behaviour.

#### IV. CONCLUSION

We have found that wavelet packet based compression schemes as allowed in JPEG2000 Part 2 can improve the accuracy of iris recognition schemes as compared to the dyadic JPEG2000 Part 1 compression technique. However, this is only true for the (computationally expensive) rate-distortion optimizing approach but neither for cost-function based best basis schemes, nor the fixed WSQ decomposition scheme.

As a side-result, we have identified the scenario when compressing only one image in the matching process as being significantly superior to the scenario when both images involved in matching have been compressed. Also, the ranking among several different iris feature extraction / matching techniques with respect to accuracy in terms of EER has turned out NOT to be preserved under severe compression. In particular, the DCT-based scheme of Monro *et al.* is not able to operate under severe JPEG2000 compression.

#### REFERENCES

[1] C. Rathgeb, A. Uhl, and P. Wild, "Iris recognition: From segmentation to template security," *Advances in Information Security*, vol. 59, Springer Verlag, 2013.

[2] J. Daugman and C. Downing, "Effect of severe image compression on iris recognition performance," *IEEE Trans. Information Forensics and Security*, vol. 3, no. 1, pp. 52–61, 2008.

[3] R. W. Ives, R. P. Broussard, L. R. Kennell, and D. L. Soldan, "Effects of image compression on iris recognition system performance," *Journal of Electronic Imaging*, vol. 17, issue 1, pp. 011015-1-011015-5, 2008.

[4] S. Rakshit and D. M. Monro, "An evaluation of image sampling and compression for human iris recognition," *IEEE Trans. Information Forensics and Security*, vol. 2, no. 3, pp. 605–612, 2007.

[5] G. S. Kostmayer, H. Stögner, and A. Uhl, "Custom JPEG quantization for improved Iris recognition accuracy," in *Proc. the 24th IFIP International Information Security Conference 2009 (IFIP SEC'09 on Emerging Challenges for Security, Privacy and Trust. eedings)*, pp. 76-86, IFIP AICT, 297, Springer Verlag, May 2009.

[6] K. Horvath, H. Stögner, and A. Uhl, "Effects of JPEG XR compression settings on iris recognition systems," in *Proc. the 14th International Conference on Computer Analysis of Images and Patterns (CAIP 2011)*, 2011, vol. 6855, pp. 73–80.

[7] D. Monro, S. Rakshit, and D. Zhang, "DCT-based iris recognition," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 29, no. 4, pp. 586–595, 2007.

[8] S. Kasaei, M. Deriche, and B. Boashash, "A novel fingerprint image compression technique using wavelet packets and pyramid lattice vector quantization," *IEEE Trans. Image Processing*, vol. 12, no. 11, pp. 1365–1378, 2002.

[9] B. Mühlbacher, T. Stütz, and A. Uhl, "JPEG2000 Part 2 wavelet packet subband structures in fingerprint recognition," in *Proc. Visual Communications and Image Processing 2010 (VCIP'10)*, 2010, pp. 77442C-1-77442C-10.

[10] J. Hämmerle-Uhl, M. Karnutsch, and A. Uhl, "Recognition impact of JPEG2000 part 2 wavelet packet subband structures in polar iris image compression," in *Proc. the 19th International Conference on Systems, Signals and Image*, 2012, pp. 13–16.

[11] J. Hämmerle-Uhl, M. Karnutsch, and A. Uhl, "Evolutionary optimisation of JPEG2000 part 2 wavelet packet structures for polar

Iris image compression," in *Proc. the 18th Iberoamerican Congress on Pattern Recognition (CIARP'13)*, 2013, pp. 391-398.

[12] G. M. Jeong, C. Kim, H. S. Ahn, and B. J. Ahn, "JPEG quantisation table design for face images and its application to face recognition," *IECE Transactions*, vol. 01, no. 89-A, pp. 2990-2993, 2006.

[13] D. Taubman and M. Marcellin, *JPEG2000 — Image Compression Fundamentals, Standards and Practice*, Kluwer Academic Publishers, 2002.

[14] R. R. Coifman and M. V. Wickerhauser, "Entropy based methods for best basis selection," *IEEE Trans. Information Theory*, vol. 38, no. 2, pp. 719–746, 1992.

[15] T. Stütz and A. Uhl, "Efficient and rate-distortion optimal wavelet packet basis selection in JPEG2000," *IEEE Trans. Multimedia*, vol. 14, no. 2, pp. 264–277, 2012.

[16] T. Stütz, B. Mühlbacher, and A. Uhl, "Best wavelet packet bases in a JPEG2000 rate-distortion sense: The impact of header data," in *Proc. the IEEE International Conference on Multimedia & Expo, ICME '10*, Singapore, July 2010, pp. 19–24.

[17] K. Ramchandran and M. Vetterli, "Best wavelet packet basis in a rate-distortion sense," *IEEE Trans. Image Processing*, vol. 2, no. 2, pp. 160-175, 1993.

[18] N. M. Rajpoot, R. G. Wilson, F. G. Meyer, and R. R. Coifman, "Adaptive wavelet packet basis selection for zerotree image coding," *IEEE Trans. Image Processing*, vol. 12, no. 12, pp. 1460–1472, 2003.

[19] J. N. Bradley, C. M. Brislawn, and T. Hopper, "The FBI wavelet/scalar quantization standard for greyscale fingerprint image compression," in *Proc. SPIE*, Apr. 1993, vol. 1961, pp. 293–304.

[20] J. G. Ko, Y. H. Gil, J. H. Yoo, and K. I. Chung, "A novel and efficient feature extraction method for iris recognition," *ETRI Journal*, vol. 29, no. 3, pp. 399 – 401, 2007.

[21] L. Ma, T. Tan, Y. Wang, and D. Zhang, "Efficient iris recognition by characterizing key local variations," *IEEE Trans. Image Processing* vol. 13, pp. 739-750, 2004.



**Jutta Hämmerle-Uhl** is a post-doctoral researcher at the Department of Computer Sciences, University of Salzburg, Austria, where she is a member of the Multi Media Signal Processing and Security (WaveLab) group. Her scientific research interests include biometric security and robustness (physiological modalities captured by cameras) and image and video compression. Her further professional interests are in software development and database technology.



**Ernst Tillian** is a master student at the Department of Computer Sciences, University of Salzburg, Austria. Until recently, he was a senior project manager at SkiData GmbH working on access control technology for events. His research interests include biometrics, data security and IT security in general.



**Andreas Uhl** is currently a full professor at the Department of Computer Sciences, University of Salzburg, Austria where he is heading the Multi Media Signal Processing and Security (WaveLab) group. His research interests include multimedia security (with emphasis on visual data encryption and watermarking), biometric security and robustness (physiological modalities captured by cameras), medical image analysis, and image and video compression and processing.

He is associate editor of ACM TOMCCAP, EURASIP Image and Video Processing, Signal Processing: Image Communication and the ETRI Journal. Moreover, he is a member of various program committees, e.g. IEEE ICIP, EURASIP EUSIPCO, ACM Information Hiding & Multimedia Security, IFIP Communications and Multimedia. In 2014, Andreas Uhl acts as a general chair for the 2<sup>nd</sup> ACM Workshop on Information Hiding and Multimedia Security, held in Salzburg, Austria. He is a member of the IEEE and the ACM.