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Part based bit error analysis of iris codes

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ABSTRACT

In order to effectively use iris patterns in biometric recognition, there is value in knowing how bit errors in iris codes are distributed. In this work, the iris is considered in a part-based framework as rings and sectors. A mean normalised bit error is defined as the bit error averaged over the entire part and over an ensemble of images. The distribution of this error for genuine comparisons is investigated as a function of radius (ring) and angle (sector) for a range of factors more comprehensively than previous studies of consistency of iris codes. Two iris recognition systems and three data sets are used. The effect of residual segmentation errors after automated segmentation is checked, and masks are manually refined to obtain segmentation error free data for further investigation. The effect of factors such as capture sensor, re-sampling, input iris image resolution, filter type and encoding scheme, and changes in pupil size is systematically investigated. Results confirm the finding in previous works that the pupillary and limbic boundaries are more error-prone than the middle region of the iris. This study further confirms that this V-shaped radial trend is not significantly disturbed by any of the above factors other than pupil size changes. Both pupil dilation and constriction result in increased bit errors which no longer show a dip in the middle region of the iris. The distribution of errors as a function of angle is approximately uniform regardless of the factor investigated but shows a small decrease towards the sectors near the eye corners.

1. Introduction

The richness of the iris texture and its variability across individuals make it a very reliable biometric trait for personal authentication [1]. However, texture information within the iris is not uniform, and bits in an iris code differ in their consistency from one sample to another for the same identity.

Different approaches have been proposed to investigate the differences between regions of the iris in their contributions to iris recognition performance. An early approach by Pereira and Veiga [2] analysed all possible combinations of five out of ten concentric iris rings to improve the performance of an iris recognition system. If rings are numbered from the pupillary boundary out to the limbus as 1–10, the best performance was obtained when using rings 2, 3, 4, 5 and 7. To complete the analysis [3], they divided the iris into a greater number of concentric rings and used a genetic algorithm to determine those that led to the best performance. Results showed that the selected rings were mainly located in the central regions of the iris.

Hollingsworth et al. [4] demonstrated the existence of fragile or inconsistent bits, which are defined as bits that have a substantial probability of changing from a 0 to a 1 or vice versa in iris codes of the same iris. Given a number of test images, the percentage of images in which a particular bit of the iris code changes measures the inconsistency of that bit. A bit is said to be fragile at $p\%$ consistency threshold if it changes in at least $p\%$ of the images. Using a consistency threshold of 40%, best results were obtained for rings 5–12 out of twenty (or 2–6 out of ten approximately) for rings numbered in ascending order from the pupillary boundary out to the limbus. This information was exploited by masking the fragile bits before the comparison stage in order to increase the recognition accuracy. The authors of this work also found that certain bits are consistent even across out-of-focus and noisy images. Rathgeb et al. [5] used the previous work as a reference and computed a mask in which the consistency at each bit position was defined as the difference between the estimated probabilities of occurrence of intra-class and inter-class errors. Tan and Kumar [6] exploited the temporal intra-class information in the feature space to derive a stability map which indicates the consistency of bits in iris codes.

Broussard et al. [7] and Hilal et al. [8] calculated the recognition accuracy achieved by different iris regions in order to evaluate their contribution to the comparison decision. In [7], rings 4–8 out of ten were reported to be the most consistent, whereas in [8], rings 2 and 3 out of ten performed the best, followed by rings 1, 4 and 5. In both cases rings are numbered in ascending order from the pupillary boundary out to the limbus.

Results reported in all previous approaches seem to indicate that

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texture information located in the central region of the iris is more consistent, and the maximum consistency is reached closer to the pupillary boundary than to the limbus. However, some differences exist in the results obtained for rings near the pupillary boundary which should be further investigated.

Inconsistencies in different regions of the iris could be influenced by factors other than texture information. Potential causes of inconsistencies, such as segmentation [4,8], normalisation [8], template and filter size [7], filter type [4], and iris alignment [4] have been previously investigated considering different criteria. Fragile bits [4], probabilities of occurrence of intra-class and inter-class errors [5], recognition accuracy [7,8] or decidability [8] are some of these criteria. Although experiments confirmed that these factors affect consistency, the lack of a common testing framework makes it difficult to compare the different effects in a quantitative manner. A methodology is proposed here to comprehensively analyse the consistency of bits of different iris regions including additional factors, such as changes in capture sensor, resampling parameters, resolution, and changes in pupil size.

In this work, irides are divided into radial partitions or rings as well as angular partitions or sectors for error analysis. Statistics of bit errors calculated using Hamming distance are computed for genuine and impostor distributions as functions of radius and angle. The results provide insight into the most effective manner in which iris texture can be used considering the spatial distribution of bit errors in iris codes. Three data sets and two iris recognition systems are used in the experiments.

This paper is organised as follows. In Section 2, the proposed error analysis is described in detail. The data sets and iris recognition systems used in the experiments are described in Section 3. A list of factors that affect the distribution of bit errors within the iris is presented in Section 4, together with tests to quantify their effect. Conclusions are outlined in Section 5.

2. Proposed error analysis method

An iris recognition system has four main stages: data acquisition, pre-processing, feature extraction, and comparison (see Fig. 1). Once a 2D image of the eye has been captured using an iris sensor, the iris region is isolated from other structures in its vicinity during the segmentation and masking stages. The resultant iris region is then unwrapped into a rectangular block of fixed dimensions during the normalisation stage. The normalised iris image is then subjected to filtering, and the ensuing phasor responses are encoded into a bit string referred to as an iris code. In the comparison stage, the dissimilarity between two iris codes is computed. The mask generated during the pre-processing stage is used to prevent degraded regions from being compared. Both the iris code and the mask can be viewed as binary vectors. It is assumed here that a mask value is 1 where a bit is retained and 0 where a bit is masked away. The error analysis presented in this research is based on the number of bits that differ between the iris codes of different iris samples.

Different approaches can be used to implement the different stages of an iris recognition system. In this paper, the binary iris codes and masks required to compute the bit errors are obtained from two open source iris recognition systems, $\text{OSIRIS}_{\text{v4.1}}$ [9] and $\text{USIT}_{\text{v1.0.3}}$ [10]. Details of these systems are provided in Section 3.

The *normalised bit error* between two iris codes $\{\mathbf{C}1, \mathbf{C}2\}$ whose mask bit vectors are denoted $\{\mathbf{M}1, \mathbf{M}2\}$ is defined as the number of bits that differ between the unmasked portions of the iris codes as a fraction of the total number of bits that are compared. This dissimilarity metric is also known as normalised Hamming distance or fractional Hamming distance. The *normalised bit error* is calculated using Eq. (1), where ⊕ and & are the bitwise-XOR and the bitwise-AND operation respectively, and || represents the L1 norm.

$$\epsilon = \frac{|(\mathbf{C}1 \oplus \mathbf{C}2)\ \&\ (\mathbf{M}1\ \&\ \mathbf{M}2)|}{|\mathbf{M}1\ \&\ \mathbf{M}2|} \tag{1}$$

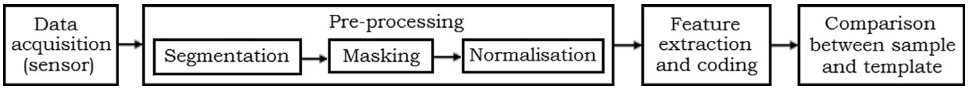

Fig. 1. Typical stages of iris recognition.

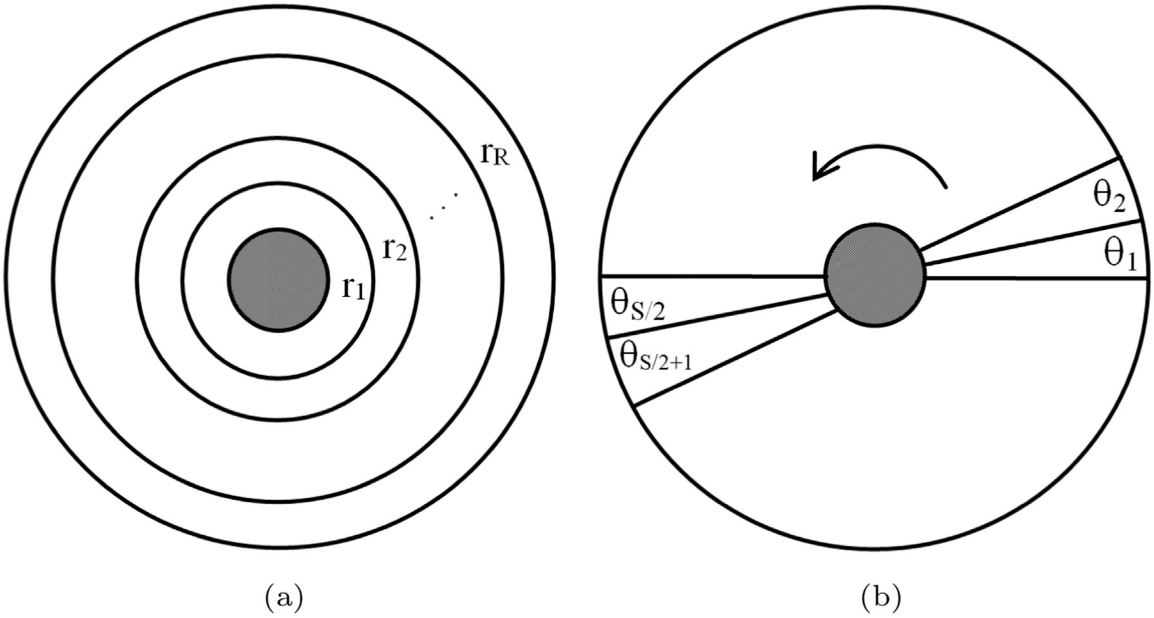

Fig. 2. Iris partitioning. (a) Radial partitioning. (b) Angular partitioning.