HUMAN IRIS IDENTIFICATION VIA LOW-COMPLEXITY CIRCULAR PERIODICITY TRANSFORM

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ABSTRACT

In this paper, we propose a low-complexity *circular periodicity transform* (CPT) for human iris identification. The proposed CPT enhances the standard periodicity transform by enabling the extraction of a wide spectrum of periodic patterns hidden in human iris. A computation-efficient architecture is developed for accurate iris identification with minimal hardware cost. The CPT-based iris identification system achieves up to 99.2% recognition rates with $21.8\% - 56.2\%$ reduction in computation complexity as compared with the standard periodicity transform. The proposed CPT in combination with architecture optimizations address the challenges in single-chip implementation of biometric systems.

1. INTRODUCTION

Biometric recognition has become the key technology in various secure identification and personal verification systems. Biometric systems exploit distinctive physiological (face, fingerprints, iris, etc.) or behavioral (gait, handwriting, etc.) features for automatically recognizing individuals. Among these features, human iris possesses a higher level of complexity and uniqueness than many other biometrics [1]. Hence, iris identification is becoming a promising biometric solution to address the ever growing demand on individual authentication.

Existing iris identification systems [2], [3] are built upon standard decomposition algorithms such as wavelet transform. Wavelet transform decomposes data sequences using a set of scaling functions at various resolution levels. This approach is effective in characterizing scaling similarities inherent in uniform texture. Human iris is composed of annular texture that is intuitively different from uniform texture. Statistical analysis reveals substantial repetitive patterns in concentric circles of human iris. Standard wavelet transform and its derivatives do not explicitly search for such patterns.

Our past work [4] utilizes a time-domain algorithm, called the periodicity transform (PT) [5], to extract the intrinsic features in human iris. Periodicity transform was developed primarily to study the mathematical significance of periodicities, repetitions and regularities. However, standard PT is inadequate in analyzing low-frequency periodic components, which account for a small but essential portion of biometric information in human iris. In this paper, we propose an algorithm improvement referred to as the *circular periodicity transform* (CPT). It is shown that the proposed CPT is capable of extracting a wide spectrum of periodic components in human iris. With the emerging applications such as homeland security, VLSI implementation of biometric systems becomes almost the only scalable solution to sustain the increasing demand on real-time performance. A low-complexity CPT architecture is developed for accurate iris identification with minimal computation cost. The CPT-based iris identification system achieves up to 99.2% recognition rates with $21.8\% - 56.2\%$ reduction in computation complexity as compared with the standard PT.

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2. PERIODICITY TRANSFORM

The periodicity transform (PT) [5] detects repetitive patterns in a sequence by projecting the sequence onto periodic subspaces $\mathcal{S}_p$, $p \geq 1$, where

$$\mathcal{S}_p = \{x(k) : x(k+p) = x(k) \text{ for all integers } k\}. \tag{1}$$

The periodic subspace $\mathcal{S}_p$ is spanned by a set of p-periodic basis vectors $\delta_p^s(j)$, defined as

$$\delta_p^s(j) = \begin{cases} 1 & \text{if } (j-s) \bmod p = 0, \\ 0 & \text{otherwise}, \end{cases} \tag{2}$$

where j is the time index and $s = 0, 1, \ldots, (p-1)$ represents the time shift.

From (2), $\langle \delta_p^{s1}, \delta_p^{s2} \rangle = 0$ for $s1 \neq s2$, where $\langle \cdot \rangle$ denotes the inner product defined as $\langle x, y \rangle = \sum_k x(k)y(k)$. Thus, the basis vectors δ_p^s, $s = 0, 1, \ldots, (p-1)$, are orthogonal of each other in subspace $\mathcal{S}_p$.

Let $x = \{x(0), x(1), \ldots, x(N-1)\}$ be an N-point sequence. The PT projects x onto periodic subspaces $\mathcal{S}_p$, $p \geq 1$.

The resulted component at $\mathcal{S}_p$, denoted by x_p, is a linear combination of the basis vectors δ_p^s, i.e.,

$$x_p = \lambda_p^0 \delta_p^0 + \lambda_p^1 \delta_p^1 + \ldots + \lambda_p^{p-1} \delta_p^{p-1}, \tag{3}$$

where $\Lambda_p = \{\lambda_p^0, \lambda_p^1, \ldots, \lambda_p^{p-1}\}$ is the coefficient set, calculated by

$$\lambda_p^s = \frac{1}{N/p} \sum_{k=0}^{N-1} x(k) \delta_p^s(k), s = 0, 1, \ldots, p-1. \tag{4}$$

According to the projection theorem [5], the original sequence x can be approximated by a sum of periodic components x_p, $p \geq 1$. These periodic components characterize the repetitive patterns in sequence x.

3. IRIS IDENTIFICATION VIA CIRCULAR PERIODICITY TRANSFORM (CPT)

In this section, we present an iris identification solution based on the circular periodicity transform (CPT). The proposed CPT enables us to extract a wide spectrum of periodic components inherent in human iris. We also discuss an algorithm transformation for low-complexity implementation.

3.1. Circular Periodicity Transform (CPT)

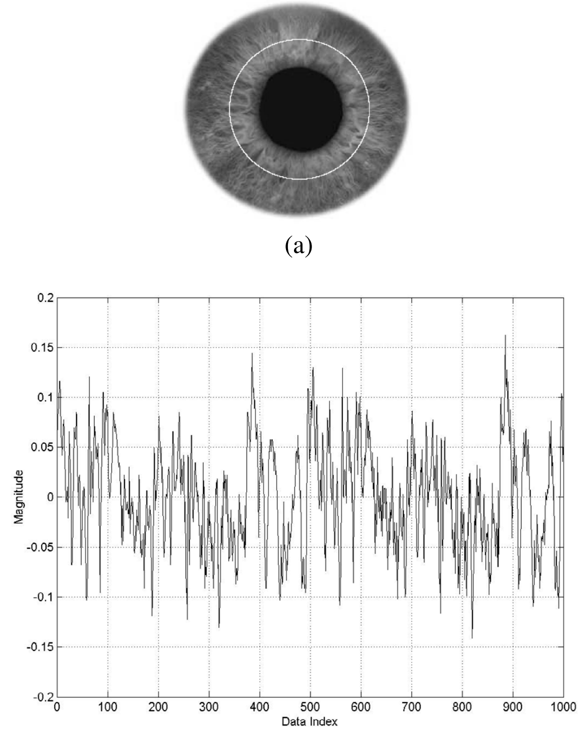
Human iris as shown in Fig. 1(a) exhibits a regular annular texture. The data sequence collected from a concentric circle exhibits strong repetitive patterns (see Fig. 1(b)), whereas different concentric circles contain less discernible but statistically significant variations in repetitive patterns. Employing periodicity transform, we can extract these repetitive patterns by projecting the concentric circles onto various periodic subspaces.

Standard PT as expressed in (3), (4) relies upon time-domain correlations with basis vectors to extract the periodic components hidden in a data sequence. For low-frequency components (large values of p), only a few data samples are available for correlation computation. For example, if $p > N/2$, where N is the length of data sequence, at most only two data samples will be calculated for each time shift s (see (4)). Thus, standard PT is not feasible to extract low-frequency components. Due to this constraint, the maximum period $p_{\max}$ for decomposition is typically chosen to be less than $N/2$.

Low-frequency periodic components (e.g., $p > N/2$) contain essential biometric information of human iris. Hence, we need an effective method to exact these components for reliable iris identification. In this paper, we propose a circular periodicity transform (CPT) for this purpose.

Consider a circular data sequence x^c obtained by repeating an N-point sequence x periodically outside its boundaries, i.e.,

$$x^c(k) = x(k \bmod N), \tag{5}$$



(a)

(b)

Fig. 1. Human iris samples. (a) Iris image. (b) A date sequence collected from the concentric circle of the iris image.

where k is the time index. The circular periodicity transform of sequence x is defined as

$$x_p^c = \vartheta_p^0 \delta_p^0 + \vartheta_p^1 \delta_p^1 + \ldots + \vartheta_p^{p-1} \delta_p^{p-1}, \tag{6}$$

$$\vartheta_p^s = \frac{1}{N} \sum_{k=0}^{pN-1} x^c(k) \delta_p^s(k), \tag{7}$$

where x_p^c is the p-periodic component of x^c and $\vartheta_p^s, s = 0, 1, \ldots, p-1$, are the coefficients of CPT.

From (5), x^c is an N-periodic sequence. According to the projection theorem [5], x^c can be approximated by a sum of periodic components x_p^c with periods smaller than N, i.e.,

$$x^c \approx x_1^c + x_2^c + \ldots + x_{N-1}^c, \tag{8}$$

where x_p^c, $p = 1, 2, \ldots, N-1$, are given by (6).

It can be shown that for small periods (e.g., p is a fraction of N), $\vartheta_p^s = \lambda_p^s$, where λ_p^s is obtained from standard PT on sequence x (see (4)). Thus, $x_p^c = x_p$ indicating that the proposed CPT preserves the decomposition results of PT for high-frequency components. Additionally, the proposed CPT is able to extract low-frequency components, say x_p^c for $p > N/2$. These low-frequency components are also a part of sequence x. As a result, by combining PT for high-frequency components and CPT for the other side, we can effectively extract a wide spectrum of periodic components in human iris for reliable iris identification.

3.2. Algorithm Transformation for Low-Complexity Implementation

The implementation of CPT is computation intensive due to the correlations involved in projecting data sequences onto periodic subspaces over different time shifts. In this section, we discuss an algorithm transformation that significantly reduces the computation cost of CPT.

Consider two periodic subspaces $\mathcal{S}_p$ and $\mathcal{S}_q$, where p is a factor of q,

$$q = mp, m > 1. \tag{9}$$

From (7), the projection of sequence x^c onto periodic subspace $\mathcal{S}_p$ can be expressed as

$$\begin{aligned} N\vartheta_p^s &= \sum_{k=0}^{Np-1} x^c(k)\delta_p^s(k) = \sum_{k=0}^{N-1} x^c(s+kp) \\ &= \sum_{i=0}^{m-1}\left[\sum_{j=0}^{(N/m)-1} x^c(s+(mj+i)p)\right], \end{aligned} \tag{10}$$

where s is the time shift ranging from 0 to $p-1$. The last equation in (10) is obtained by substituting $k = \{mj, mj+1, \ldots, mj+(j-1)\}$ for $0 \le j \le (N/m)-1$. Employing (9), the sum inside the brackets can be rewritten as

$$\begin{aligned} &\sum_{j=0}^{(N/m)-1} x^c(s+(mj+i)p) \\ &= \sum_{j=0}^{(N/m)-1} x^c((s+ip)+jq) = \frac{N}{m}\vartheta_q^{s+ip}. \end{aligned} \tag{11}$$

Substituting (11) into (10), we get

$$\vartheta_p^s = \frac{1}{m}\sum_{i=0}^{m-1}\vartheta_q^{s+ip}. \tag{12}$$

We prove in (12) that the CPT projections of sequence x^c onto subspace $\mathcal{S}_p$ can be obtained directly from the projections at subspace $\mathcal{S}_q$, provided that p is a factor of q (see (9)). This greatly simplifies the computation of CPT. We can employ a similar approach in [4] by partitioning all the periodic subspaces into a few prime subspaces, i.e.,

$$\mathbb{S}_i = \bigcup_i \mathcal{S}_{mi}, \tag{13}$$

where $\mathbb{S}_i$ is a prime subspace and i is a prime number. Applying (12) in each prime subspace, the CPT projections at $\mathcal{S}_i$ can be derived from the CPT projections at $\mathcal{S}_{m_1 i}$, and the CPT projections at $\mathcal{S}_{m_1 i}$ can be derived from those on $\mathcal{S}_{m_2 i}$ (m_1 is a factor of m_2) and so on. It can be shown that as many as half of the CPT projections can be obtained using (12) without performing computation-intensive correlations.

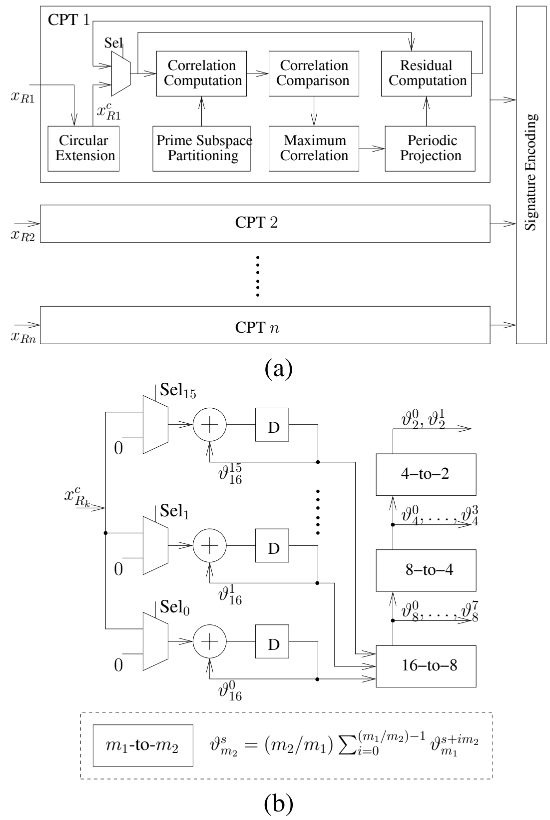


Fig. 2. The proposed iris identification system. (a) Signature generation unit. (b) CPT architecture.

4. IMPLEMENTATION AND PERFORMANCE EVALUATION

Employing the proposed CPT, we develop a computation-efficient iris identification system. The system extracts intrinsic iris features using low-complexity CPT and encodes these features into a biometric signature. The iris signature is identified through signature matching logic.

The signature generation shown in Fig. 2 employs the *Best Correlation* criterion [5] to decompose iris data sequences. Here, x_{R_k} denotes the data sequence collected from the concentric circle R_k of an iris image. The periodic subspaces are partitioned into prime subspaces (see (13)). Within each prime subspace, the correlations between x_{R_k} and periodic basis vectors are calculated using (12). Note that there are multiple ways to partition the prime subspaces. For example, S_6 can be assigned to either $\mathbb{S}_2$ or $\mathbb{S}_3$. This provides flexibility to balance the computation load among prime subspaces in order to optimize the overall performance.

Figure 2(b) shows the architecture for implementing CPT on an example prime subspace, $\mathbb{S}_2$, assuming that the length of x_{R_k} is 17. Note that $x^c_{R_k}$ is the circular version of x_{R_k} obtained from (5). The projection vector $\{\vartheta_{16}^0, \vartheta_{16}^1, \ldots, \vartheta_{16}^{15}\}$ denotes the 16-periodic component extracted from $x^c_{R_k}$ using

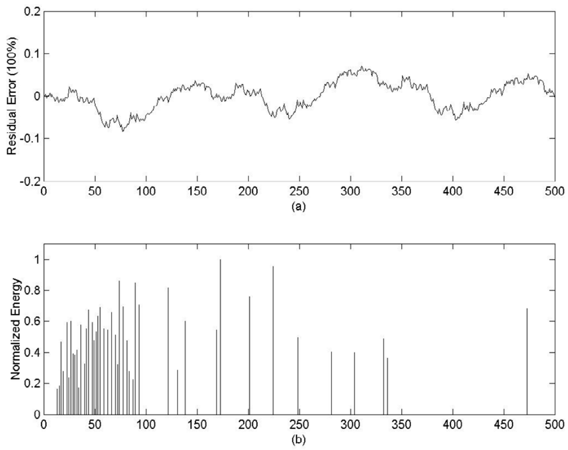


Fig. 3. Experimental results. (a) Residual errors after the standard PT. (b) Energy distribution of the periodic components extracted by the proposed CPT.

CPT. Once this component is calculated, the projections onto other periodic subspaces S_p in $\mathbb{S}_2$ can be derived directly using (12) without performing the redundant correlations. Thus, the proposed CPT-based architecture is able to eliminate up to 50% of the correlations. This highly parallel and resource-sharing architecture performs efficient computation without incurring any performance degradation.

The periodic components extracted from the sequences $x_{R_1}, x_{R_2}, \ldots, x_{R_n}$ characterize the intrinsic features of human iris. These components are encoded into a biometric signature [4] and compared against the enrolled iris signatures in the database. Iris identification employs a minimum-mean-squared-error (MMSE) estimator to quantify the difference between iris signatures.

We evaluate the performance of the proposed iris identification system using the CASIA iris image database [6]. Figure 3(a) shows the residual errors after performing standard PT on a data sequence ($N = 500$) collected from the concentric circle of an iris image. In comparison with Fig. 1(b), the residual errors contain a substantial amount of low-frequency components. Figure 3(b) shows the energy distribution of all the periodic components extracted by CPT, where the low-frequency components ($P > N/2$) have been successfully extracted. Table 1 compares the performance under different sets of design specifications. Here we choose the number of data sequences from two to eight. As the number of data sequences increases, error rates are reduced from 13.5% to 0.81% because more iris features are taken into account. Furthermore, the computation complexity (measured in the number of addition operations) is also reduced from 21.8% to 56.2% as compared with standard PT. This is due to the fact that as $p_{\max}$ increases with the number of data sequences, we

Table 1. Performance of iris identification.

Date Set	2	4	6	8
$p_{\max}$	150	240	440	600
Error Rate (%)	13.5	6.3	2.4	0.81
Savings (%)	21.8	39.7	49.3	56.2

have flexibility to partition prime subspaces and consequently more redundant correlation computations can be eliminated. Note that the error rates are improved by about 10% from the previous system [4] where low-frequency components were not accounted for. Also, this system is less affected by the irrelevant information such as eyelids and eyelashes, which results in about 10% pre-processing failures in a 2-D wavelet based identification system [2]. The repetitive patterns can be reliably extracted from the incomplete concentric circles obstructed by eyelids and eyelashes.

5. CONCLUSIONS

The ever growing demand on individual authentication presents an opportunity for single-chip implementation of biometric systems. In this paper, we propose a low-complexity *circular periodicity transform* (CPT) for human iris identification. The proposed CPT enhances the standard periodicity transform by enabling the extraction of a wide spectrum of periodic patterns hidden in human iris. A computation-efficient architecture is developed for accurate iris identification with minimal hardware cost. Future work is being directed towards single-chip silicon integration of the proposed CPT-based iris identification system. More detailed studies, such as power-speed-complexity tradeoffs, single-chip design issues, and comparison with the existing systems will be carried out.

6. REFERENCES

[1] A. K. Jain, R. Bolle, and S. Pankanti, *Biometrics: Persional Identification in Network Society*, Kluwer Academic Publishers, 1999.

[2] W. S. Chen, K. H. Chih, S. W. Shih, and C. M. Hsieh, "Personal identification technique based on human iris recognition with wavelet transform," *Proceedings of ICASSP'05*, vol.2, pp. 949-952, March 2005.

[3] L. Man, T. Tan, Y. Wang, and D. Zhang, "Personal identification based on iris texture analysis," *IEEE Trans. Patt. Analy. Mach. Intell.*, vol. 25, pp. 1519-1533, Dec. 2003.

[4] L. Wang, "Algorithm optimization and architectural design of periodicity transform for biometric applications," *IEEE Workshop on Signal Processing Systems (SIPS)*, 2005, accepted.

[5] W. A. Sethares and T. W. Staley, "Periodicity transforms," *IEEE Trans. Signal Processing*, vol. 47, pp. 2953-2964, Nov. 1999.

[6] CASIA Iris Image Database, www.sinobiometrics.com.