

Ambient Temperature Invariant Infrared Face Recognition based on Discrete Wavelet Transform

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Abstract—The influence of ambient temperature is a principal challenge of the use of thermal face images for face recognition. This paper proposes a weighted wavelet sub-bands method for infrared face recognition under variable ambient temperatures. The wavelet transform can decompose an infrared image into different levels of approximation and detail sub-bands. The influence of ambient temperature on different sub-bands is different. Based on discrimination criterion, the optimization model is constructed to strengthen the features robust to ambient temperature, and weaken the features vulnerable to ambient temperature. By minimizing the criterion function, we can assign the optimal weights to corresponding sub-bands. Finally, the optimization method is applied to variable ambient temperatures infrared face recognition to verify its efficiency. The experiments demonstrate that the proposed ambient temperature invariant method is feasible and can significantly improve performance of infrared face recognition

Keywords—infrared face recognition; discrete wavelet transform; ambient temperature invariant features; weighted sub-bands; discrimination criterion

I. INTRODUCTION (HEADING 1)

Human face recognition plays an increasingly important role in a wide of application, such as criminal identification, credit card verification and scene surveillance [1]. There are many face recognition researches in the past decades, based mainly on visible spectrum. The main limitation of visible face recognition is prone to illumination, pose, expression, which are evitable in real-world conditions [2]. Whereas far infrared or thermal imaging faces can solve the limitations visible face recognitions, because they are invariant to illuminations. With the thermal infrared imagery technology development, the thermal infrared cameras have decreased their price significantly and obtained better resolution and quality. As a result, thermal infrared face recognition became a good issue for high performance face recognition in the last few years. However, the thermal images also have their own deficiencies [3]: a) changes in ambient temperature, b) modifications of the metabolic process of the subject, and c) variable sensor response when the camera is working for long periods of times. These factors make the performance of infrared face recognition drops dramatically if no invariant feature methods are used [6]. This article is devoted to the

ambient temperatures problem. There are two categories methods dealing with the ambient temperatures: ambient temperature normalization and invariant ambient temperatures features extraction. To infrared image temperature normalization, Kakuta [7] proposed an infrared image temperature normalization method based on residual value between reference ambient temperature and unknown ambient temperature, which is on the assumption that the different regions of infrared image have the same temperature changes with the variant ambient temperatures. Xie [11] proposed an infrared face temperature normalization method based on second order polynomial model. On the other hand, ambient temperature invariant representation method receives only scant attention. In this paper, we focus on the ambient temperature invariant features to improve the performance of thermal infrared face recognition.

It was indicated by Professor Wilder [8] that the influence of ambient temperature on thermal image was essentially similar to that of illuminations on visible images. Goh et al [4] proposed wavelet based illumination invariant preprocessing in face recognition. They decomposed a facial image into low and high pass sub-bands using discrete wavelet transform(DWT) decomposition and set the illumination component(low-pass part) as zero. Cao et al [5] further improved the illumination invariant face representation based on DWT, which applied the wavelet denosing theory to retain the noise part as invariant face features. In those methods, the approximation sub-band is discard, which contains important discrimination information. Therefore, in spite of the simple algorithms and low complexity, the performance of these DWT based approaches is not every high [13].

Considering the low resolution of infrared facial images, the approximation part is more important, it is interesting to make an efficient DWT based invariant feature representation under variant ambient temperatures. To retain the discriminative information for infrared face recognition, a weighted wavelet sub-bands method based on DWT is proposed to deal with ambient temperature problem. In order to get the discriminative information under variable ambient temperatures, we developed a regularization criterion function after some mathematical reductions. By minimizing the criterion function, we can assign the optimal weights to corresponding sub-bands. After wavelet reverse transform, the ambient temperature invariant infrared face is used to

traditional infrared face recognition. The experiments demonstrate that the proposed method is robust and effective to solve the ambient temperatures problem for thermal infrared face recognition.

This paper is organized as follow. Section II introduces the Wavelet transform and infrared face decomposition. Section III gives the weighted wavelet sun-bands reconstruction algorithm. Section IV presents the experimental results including the methods in the comparison study. Section V gives the conclusions of this paper.

II. INFRARED FACE WAVELET DECOMPOSITION

Wavelet transform has characteristics of a series of band-pass filters, which reveal transpositional frequency and finite duration for transient analysis through adequate scales of wavelet decomposing coefficients [4, 5]. The concept of Wavelet transform was proposed by Morlet and Grossman:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad a > 0, b \in R \quad (1)$$

Where $\psi_{a,b}(t)$ is the shifted and dilated form of the mother wavelet function, a and b denote scaling factor and shift factor, respectively.

In order to determine the DWT, discretization of a and b is represented by:

$$a = a_0^m \quad (2)$$

$$b = nb_0 a_0^m \quad (3)$$

Multi-resolution analysis was first developed by Mallat which is the framework to construct orthogonal basis of wavelet. For infrared face images, 2 dimensional separable wavelet function can be derived from scaling function $\phi(x)$ and mother wavelet function $\psi(x)$,

$$\phi(x, y) = \phi(x)\phi(y) \quad (4)$$

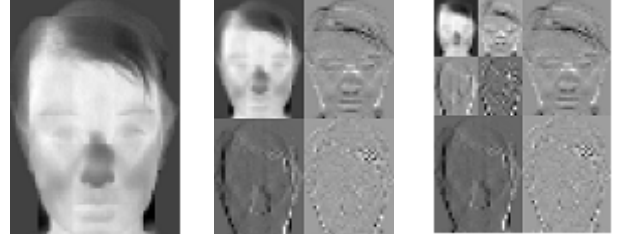
$$\psi^V(x, y) = \phi(x)\psi(y) \quad (5)$$

$$\psi^H(x, y) = \psi(x)\phi(y) \quad (6)$$

$$\psi^D(x, y) = \psi(x)\psi(y) \quad (7)$$

Where $\phi(x, y)$ is the relevant scaling function, and $\psi^i(x, y) \{i = H, V, D\}$ stands for independent and spatially oriented frequency detailed features in three directions: vertically, horizontally and diagonally. The infrared image is actually divided into four sub-bands and critically sub-sampled by applying one level 2-D discrete wavelet transform.

The DWT decomposition images are shown in Fig 1.



(a) Original Face (b) one-level DWT (c) two-level DWT

Figure 1. DWT Decomposition Images

Given an image I , first we implement an l-level two dimensional wavelet decomposition on I . Then I can be represented as follows:

$$I(x, y) = C_0 \cdot \phi(x, y) + \sum_{j=1}^l \sum_{b=H,V,D} C_j^b \cdot \psi_j^b(x, y) \quad (8)$$

$$C_0 \cdot \phi(x, y) = I_0(x, y) \quad (9)$$

$$C_j^b \cdot \psi_j^b(x, y) = I_j^b(x, y) \quad (10)$$

Where C_0, C_j^b are the corresponding wavelet transform coefficients, I_0, I_j^b are the corresponding reconstruct sub-bands.

Based on formula (8), to obtain the ambient temperature invariant image reconstruction, we need to assign the suitable weights to the DWT coefficients C_0, C_j^b .

III. THE WEIGHED SUB-BANDS RECONSTRUCTION

According to multi-resolution analysis theory, we can reconstruct the modified infrared face image by combining all the detail sub-bands of the same level [12]. The core problem of weighed sub-bands reconstruction is to assign an optimal weight α_j to each sub-bands:

$$I' = \alpha_0 I_0 + \sum_{j=1}^l \alpha_j I_j \quad (11)$$

The pyramid framework of the sub-bands and their weights can be shown in Fig 2.

I_0	I_2^v	I_1^v	α_0	α_2	α_1
I_2^h	I_2^d		α_2	α_2	
I_1^h		I_1^d	α_1		α_1

Figure 2. the Pyramid framework of 2-Level Wavelet Decomposition

Assuming there are “C” classes in all samples and “S” training samples for each person, Note that one of the S training samples is the reference infrared face image. In our weighted method, the first training sample of each person is

the reference object, the rest S-1 training samples are under variable ambient temperatures.

Suppose $I_j^{p,r}$ as the j th sub-band of the r th face of the p th person. Then denote $A_j^{p,k,r}$, $D_j^{p,k,r}$ and $C_j^{p,k,r}$ which stand for the diversity between the reference image in approximation or detail sub-bands.

$$A_j^{p,k,r} = I_0^{k,1} - I_0^{p,r} \quad (12)$$

$$D_j^{p,k,r} = I_j^{k,1} - I_j^{p,r} \quad (13)$$

$$C_j^{p,k,r} = A_j^{p,k,r} - D_j^{p,k,r} \quad (14)$$

The weighed criterion function is based on discriminant separability (SD) of pattern recognition [10]. It consists of two terms: the diversity of images with in the same person (Dw), the diversity of the images between different people (Db).

$$SD(\{\alpha_j\}) = Dw(\{\alpha_j\}) - \mu Db(\{\alpha_j\}) \quad (15)$$

$$Dw(\{\alpha_j\}) = \sum_{k=1}^C \sum_{r=1}^S \left\| \alpha_0 A_j^{k,k,r} + \sum_{j=1}^l \alpha_j A_j^{k,k,r} \right\|^2 \quad (16)$$

$$Db(\{\alpha_j\}) = \sum_{k=1}^C \sum_{r=1}^S \sum_{p=1, p \neq k}^C \left\| \alpha_0 A_j^{p,k,r} + \sum_{j=1}^l \alpha_j D_j^{p,k,r} \right\|^2 \quad (17)$$

After Simple deductions, the SD can be indicated by:

$$SD(\{\alpha_j\}) = \sum_{k=1}^C \sum_{r=1}^S \left[\left\| (l+1)\alpha_0 A_j^{k,k,r} - \sum_{j=1}^l \alpha_j C_j^{k,k,r} \right\|^2 - \mu \sum_{p=1, p \neq k}^C \left\| (l+1)\alpha_0 A_j^{p,k,r} - \sum_{j=1}^l \alpha_j C_j^{p,k,r} \right\|^2 \right] \quad (18)$$

The final purpose is to minimize the SD criterion function to obtain the optimization for the weights α_j . In this paper, we add the restrictions to parameters α_j :

$$\sum_{j=0}^l \alpha_j = l+1, \quad \alpha_j \geq 0 \quad (19)$$

The classic gradient-descent algorithm is used to optimize the weights $\{\alpha_j : 1 \leq j \leq l\}$. In this paper, for infrared face tuning, the the weights $\{\alpha_j\}$ converge very quickly.

Suppose the converging speed is η , the change of α_j for the m th iterations is

$$\Delta \alpha_j^m = \sum_{k=1}^C \sum_{r=1}^S 2\eta [(l+1)\alpha_0 A_j^{k,k,r} - \sum_{j=1}^l \alpha_j C_j^{k,k,r}] \otimes C_j^{k,k,r} - \sum_{k=1}^C \sum_{r=1}^S \sum_{p=1, p \neq k}^C 2\eta \mu [(l+1)\alpha_0 A_j^{p,k,r} - \sum_{j=1}^l \alpha_j C_j^{p,k,r}] \otimes C_j^{k,k,r} \quad (20)$$

$$\alpha_j^{m+1} = \alpha_j^m + \Delta \alpha_j^m \quad (21)$$

Where \otimes means the operator of doing the multiplication entry-wise and summing up all the multiplied entries.

IV. EXPERIMENT RESULTS AND ANALYSIS

In our experiments, the infrared face images were captured by an infrared camera Thermo Vision A40 supplied by FLIR Systems Inc [6, 11]. The infrared face database was collected under ambient temperatures from 18~32 °C. The database comprises 1000 thermal images of 50 individuals. Each person contains 20 samples. The resolution of the infrared face is 80×60.



Figure 3. Infrared face database

In this article, we initialize the experiment by setting $\mu = 1/(1.8C-1)$ and $\alpha^0 = 1$. 2-level wavelet transform is performed to construct the weighed optimal model.

To verify the weighted sub-bands method on infrared face recognition system. The weighted reconstructed infrared faces are tested for the traditional “PCA (Principal Component Analysis) + LDA (Linear Discrimination Analysis)” dimensions reduction method [9]. The one nearest neighbor classifier (NCC) is selected to final recognition. The parameter S is set to 5, 7, 10, 11, and 13. $C \times S$ samples are used for tuning in the weighted sub-bands method. $50 \times S$ samples are trained for PCA+LDA dimensionality reduction. The remaining $50 \times (20-S)$ infrared faces serve as recognition samples. The recognition results are presented in Table 1.

TABLE I. RECOGNITION RATES OF THE PORPOSED INFRARED FACE RECOGNITION

S	C	Recognition Rate
5	50	72.7%
7	50	75.6%
10	40	78.5%
11	40	81.2%
13	40	85.7%

From Table1, one can see that with the increasing of tuning samples, the recognition rate will lift. The main reason is that the more tuning samples, the more precisely our weighted sub-bands method can learn discriminative features under variable ambient temperatures.

In order to make comparisons with other methods based on wavelet domain, the Goh[4] and Cao[5] reconstructed methods were performed on the infrared face recognition. The best recognition results are listed in Table 2. It can be seen from Table 2 that our proposed weighted reconstruction method gets higher recognition rate than that of other invariant feature methods. It is because that the approximation sub-band of wavelet decomposition is very important for infrared face recognition.

TABLE II. THE RECOGNITION RATE OF DIFFERENT METHODS

None	Our method	Goh[4]	Cao[5]
31.6%	85.7%	68.8%	71.6%

V. CONCLUSIONS

In this paper, to lessen the influence of ambient temperature on infrared face recognition, we propose an ambient temperature invariant processing method based on DWT. A weighted sub-bands model is used to strengthen the features robust to ambient temperature, and weaken the features vulnerable to ambient temperature. The regularization discriminative criterion was developed to determine the optimal weights for different sub-bands. Our experiments illustrate that the weighted sub-bands method is discriminant and robust for ambient temperatures

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