A NOVEL ENERGY BASED FILTER FOR CROSS-BLINK EYE DETECTION

T. Hoang Ngan Le, Khoa Luu, Utsav Prabhu, Marios Savvides

{thihoanl, kluu, uprabhu}@andrew.cmu.edu, msavvid@ri.cmu.edu
Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA, USA

ABSTRACT

Based on the fact that eye regions may be considered as a sequence of consecutive low and high spatial frequency regions, we propose a novel and efficient filter based on Isotropic Gaussian Energy which can be used for eye detection. When applied to facial images, the designed filter highlights the eye region with a prominent pattern, which can then be localized by template matching technique such as MACE correlation filter. The proposed filter is proved useful to detect both open and closed eyes. We demonstrate the effectiveness of the proposed filter by conducting experiments on both FERET and MBGC face databases.

Index Terms— Eye detection, eye blink detection, template matching, IGE filter

1. INTRODUCTION

Human eyes play one of the most important roles in the problems of face detection, face recognition, and facial expression analysis. There are two key tasks in the eye detection problem including (1) detect the existence of eyes; (2) locate the eye positions. A robust eyes detection system requires locating eyes correctly under numerous conditions, such as illumination variations, expression, poses, and wearing eyeglasses.

Current approaches towards eye detection can be divided into two categories: active and passive. The former category uses special types of illumination [1], landmark points of eye corners, iris border points [2]. In eye detection problem, template matching techniques have proved to be useful approaches. It was firstly proposed by [3] and then improved by [4] and [5]. In these approaches, a deformable template is constructed to represent the eye regions and an energy function is defined for edges, peaks, eye corners and the geometrical structure to estimate the location of eyes. Passive approaches towards eye detection used some features such as projection [6], templates [7], Gabor wavelets [8], probabilistic framework [9]. One of the state-of-the-art face and eye detection algorithms belongs to [10], which used Adaboost with Haar-like features. In addition, some other work [11, 12, 13] have tried to overcome the limitation of the Haar feature.

In this paper, we propose a novel passive filter named Isotropic Gaussian Energy (IGE) filter based on the observation that eye region contains a special structure of high frequency - eye brow, low frequency - between eye and eyebrow, high frequency - eye, and low frequency - below part of lower eyelash. Our proposed method is constructed using both Gradient of Gaussian (GoG) and Laplacian of Gaussian (LoG) at different kernels.

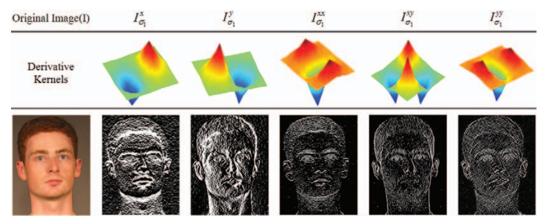

Fig. 1. GoG and LoG with the first derivative kernel $K^x_{\sigma_1}$

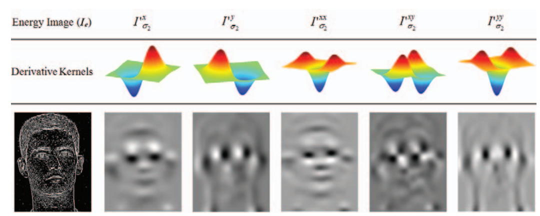

Fig. 2. GoG with the second derivative kernel $K^x_{\sigma_2}$

The rest of this paper is arranged as follows: our proposed IGE filter is detailed described in Section 2. We review the template matching technique in Section 3. Section 4 presents the eye detection and localization. Experiments are described in Section 5. Concluding remarks are provided in Section 6.

2. OUR PROPOSED IGE FILTER

The design of the IGE filter is motivated by the fact that eye regions contain a large amount of distinct gradient information. Definitely, gradient measurement on an image emphasizes regions of high spatial frequency. The eye region can be considered as a sequence of consecutive low and high spatial frequency regions (high frequency - eye brow, low frequency - between eye and eyebrow, high frequency - eye, and low frequency - below part of lower eyelash). Our proposed filter uses the following square derivative kernels in both x and y

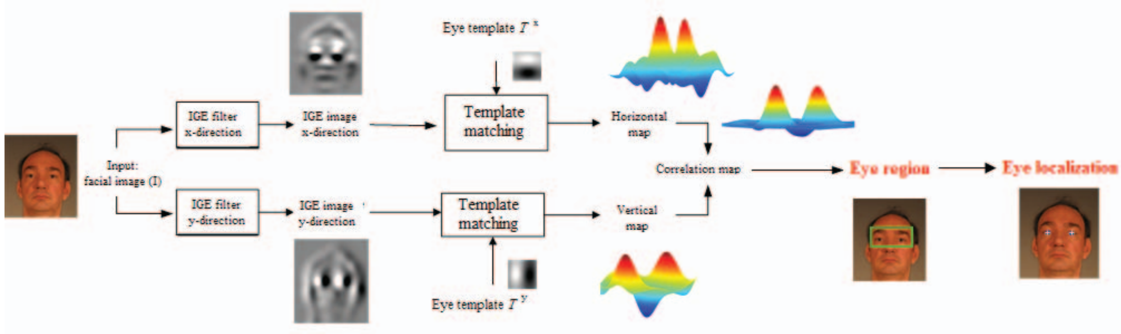

Fig. 3. Procedure of eye detection and localization

directions:

$$K_\sigma^x = \begin{bmatrix} -3\sigma & -3\sigma+1 & \cdots & 3\sigma \\ -3\sigma & -3\sigma+1 & \cdots & 3\sigma \\ \vdots & \vdots & & \vdots \\ -3\sigma & -3\sigma+1 & \cdots & 3\sigma \end{bmatrix} \quad (1)$$

$$K_\sigma^y = \begin{bmatrix} -3\sigma & -3\sigma & \cdots & -3\sigma \\ -3\sigma+1 & -3\sigma+1 & \cdots & -3\sigma+1 \\ \cdots & \cdots & \cdots & \cdots \\ 3\sigma & 3\sigma & \cdots & 3\sigma \end{bmatrix} \quad (2)$$

The 2D Gaussian filter can be defined as:

$$G(K_\sigma^x, K_\sigma^y) = \frac{1}{2\pi\sigma^2} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (3)$$

It is important to note that the behaviour of Eq.3 can be considered as the isotropic Gaussian 2D filter. Using this form of the 2D Gaussian filter, we can derive 2D GoG (Eqs. 4 and 5) and LoG (Eqs. 6, 7, and 8) filters as:

$$\nabla G(K_\sigma^x) = -\frac{K_\sigma^x}{2\pi\sigma^4} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (4)$$

$$\nabla G(K_\sigma^y) = -\frac{K_\sigma^y}{2\pi\sigma^4} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (5)$$

$$\nabla G(K_\sigma^{xx}) = \frac{(K_\sigma^x)^2 - \sigma^2}{2\pi\sigma^6} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (6)$$

$$\nabla G(K_\sigma^{yy}) = \frac{(K_\sigma^y)^2 - \sigma^2}{2\pi\sigma^6} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (7)$$

$$\nabla G(K_\sigma^{xy}) = \frac{K_\sigma^x K_\sigma^y}{2\pi\sigma^6} \exp\left(\frac{-(K_\sigma^x)^2 + (K_\sigma^y)^2}{2}\right) \quad (8)$$

The following procedure is for generating and implementing the IGE filter which is visualized in Fig.1 and Fig. 2.

1. Define derivative kernels K_σ^x and K_σ^y as shown in Eqs.1, 2 using two kernel widths σ_1 and σ_2 for each ($\sigma_1 < \sigma_2$). $K_{\sigma_1}^x$ and $K_{\sigma_1}^y$ are used to obtained all high frequencies in x-direction and y-direction. $K_{\sigma_2}^x$ and $K_{\sigma_2}^y$ are applied to emphasize the eye regions.
2. Build a 2D Gaussian filter $G(K_\sigma^x, K_\sigma^y)$ (as in Eq. 3) using the computed kernels.
3. Construct the GoG filters $\nabla G(K_{\sigma_1}^x)$ and $\nabla G(K_{\sigma_1}^y)$ as in Eqs. 4 and 5. Convolve the input image I with these filters to generate filtered images$I_{\sigma_1}^x = \nabla G(K_{\sigma_1}^x) \otimes I$ and $I_{\sigma_1}^y = \nabla G(K_{\sigma_1}^y) \otimes I$.
4. Construct the LoG filters $G(K_{\sigma_1}^{xx})$, $G(K_{\sigma_1}^{yy})$ and $G(K_{\sigma_1}^{xy})$ as in Eqs. 6, 7 and 8. Convolve the input image I with these filters, $I_{\sigma_1}^{xx} = \nabla G(K_{\sigma_1}^{xx}) \otimes I$, $I_{\sigma_1}^{yy} = \nabla G(K_{\sigma_1}^{yy}) \otimes I$, and $I_{\sigma_1}^{xy} = \nabla G(K_{\sigma_1}^{xy}) \otimes I$.
5. The energy of the edge image I_e is computed as:
$$I_e = \sqrt{I_{\sigma_1}^{yy} I_{\sigma_1}^x I_{\sigma_1}^x - 2 I_{\sigma_1}^{xy} I_{\sigma_1}^x I_{\sigma_1}^y + I_{\sigma_1}^{xx} I_{\sigma_1}^y I_{\sigma_1}^y} \quad (9)$$
6. Lastly, the x and y gradients of this energy image are computed using a GoG filter with the kernel width σ_2: $I_{(e)\sigma_2}^x = \nabla G(K_{\sigma_2}^x) \otimes I_e$ and $I_{(e)\sigma_2}^y = \nabla G(K_{\sigma_2}^y) \otimes I_e$.

The whole procedure of eye detection and localization using our proposed IGE filter is illustrated in Fig. 3.

3. TEMPLATE MATCHING TECHNIQUE

A common way to detect patterns in images is through correlation with template matching technique. Correlation is one of the most powerful techniques for template matching because of its unique shift-invariant property. Many sophisticated correlation filter design techniques have been proposed in literatures [14, 15] including Synthetic Discriminant Functions (SDF), Minimum Average Correlation Energy (MACE), Unconstrained MACE (UMACE), and Average of Synthetic Exact Filters (ASEF) filters. Template matching using correlation technique is useful when the form of the objective does not change significantly cross images. We could detect this pattern using either feature-based or template based methods. The feature-based approach, also called the local approach, uses extracted features, such as edges, corners, etc., to detect the best matching location of the pattern. Whereas the

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Proc 1: Correlation filter MACE
Input: N images, I_1, I_2, ..., I_N
Output: Correlation filter T
Procedure
    For i = 1: N
        x_i = feature_extraction (I_i) ;
        X_i = FFT(x_i);  End For
    X = [X_1, X_2, ..., X_N]
    For i = 1: N
        D = D+X_i ×X_i^*; End For
    D = D/N
    T = D^-1 X(X^+ D^-1 X)^-1 u
End Procedure

Proce 2: Matching by MACE filter
Input: Images I and template T
Output: Correlation coefficient c
Procedure
    I_f = FFT(I);
    C = I_f×T^*;
    E = Energy(I);
    c = IFFT(C)/E;
End Procedure
```

Fig. 4. Pseudo-code of template matching by MACE filter

template-based approach, or the global approach, uses the entire template of the region to maximize a comparison metric such as the sum of absolute difference of values or the cross-correlation coefficient. Fortunately, using our proposed target images are formed in the same appearance. It is evident that the eye region of the input image is prominent in the IGE filtered images in both x and y directions regardless of those eyes open or close.

We take a MACE filter robust against the illumination variations as an example. It minimizes the average correlation energy of the cross-correlation outputs while keeping the linear constraint for the origin. Correlation outputs from well-designed MACE filters typically exhibit sharp correlation peaks making the peak detection and location relatively easy and robust. Fig. 4 shows the procedures of setting the MACE filter in frequency domain (**Proc 1**) and a brief explanation of basic matching technique (**Proc 2**).

4. EYE DETECTION AND LOCALIZATION

We adopt template matching technique and take advantage of our proposed IGE filter to produce a horizontal and a vertical probability maps. These two maps are fused to extract the eye region and eye localization. From Fig. 5, the eye template in x-direction (T^x) is shown in Fig. 6(a) and the eye template in y-direction (T^y) is shown in Fig. 6(b).

The procedure of constructing horizontal map M_x using the IGE image I_x and the eye template T^x is explained in three steps: (1) Apply the IGE filter to the input facial image I in x-direction to obtain the IGE image called I_x. (2) Use **Proc 1** in which the feature extraction is defined by IGE filter to find the eye template in x-direction T^x of dimension $p \times q$. (3) Apply **Proc 2** to find all correlation coefficients of I_x and T^x and obtain the horizontal map M_x.

Similarly, the vertical map M_y is constructed by applying the IGE filter to the input image in y-direction. The correlation map M is erected by M_x and M_y. Each element P_M of M is computed by $P_M = P_{M_x} \times P_{M_y}$. The eyes region in the correlation map M is detected by searching two portions (P_1, P_2) that satisfy the following constrains:

1. The correlation coefficients at portion (P_1, P_2) are largest and $|(P_1, P_2)| \geq 0.7$.

2. The distance in horizontal between two portions is larger than $p/2$.

3. The distance in vertical direction between two portions is smaller than $q/2$.

The threshold value is chosen empirically as 0.7. The eye region R is defined as the left-top $P_{LT}(x) = min_{(P_1(x),P_2(x))}$, $P_{LT}(y) = min_{(P_1(y),P_2(y))}$ and the right-button $P_{RB}(x) = max_{(P_1(x)+q,P_2(x)+q)}$, $P_{RB}(y) = max_{(P_1(y)+p,P_2(y)+p)}$.

Eye localization is shown in Fig.7. The IGE eye image in x-direction and y-direction is firstly binarized. The eye positions (P_{x_1}, P_{x_2}) and (P_{y_1}, P_{y_2}) are determined as an intersection of margin vectors. Secondly, the eye positions are computed by averaging located positions in both directions.

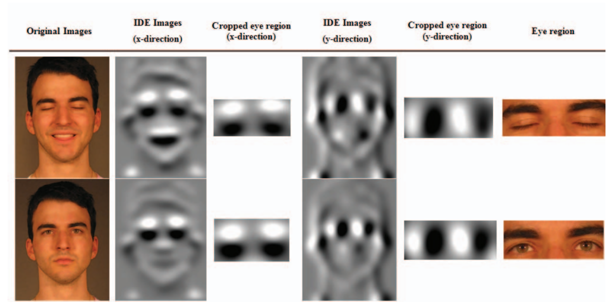

Fig. 5. IGE images of eye regions

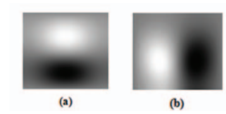

Fig. 6. Eye template of dimension $p \times q$(a): T^x, (b): T^y

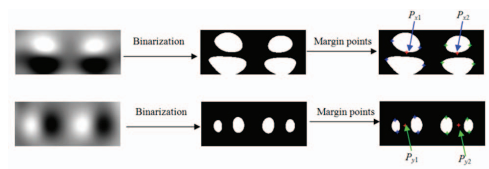

Fig. 7. Eye localization

5. EXPERIMENTS AND RESULTS

We use two testing databases including Facial Recognition Technology FERET [16] and Multiple Biometric Grand Challenge MBGC [17] databases. The FERET database composes of 2708 face images from 994 subjects. The MBGC face database contains 34,729 still frontal images of 1,036 subjects. Facial images of each subject were collected under different of illumination and facial expression. In order to con-

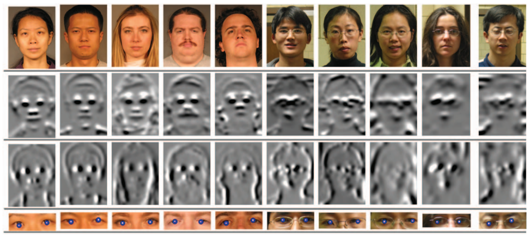

Fig. 8. DEoIG filter on MBGC database

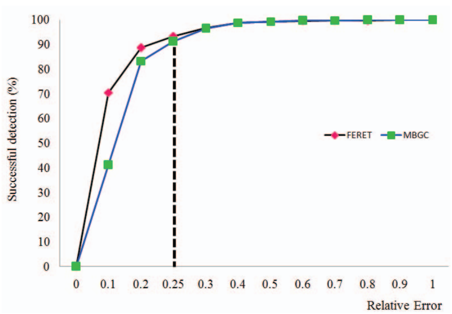

Fig. 9. Relative error

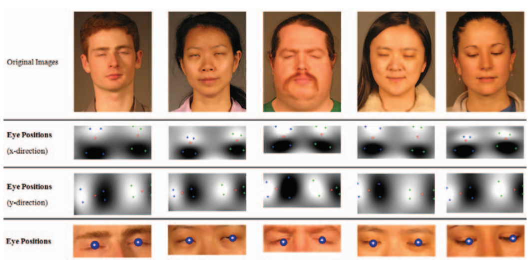

Fig. 10. Eye detection results on closed eye facial images

duct the experiment result, our proposed filter is evaluated on 5000 images of MBGC database.

To validate the performance of our IGE filter we use the criterion of relative error which is based on the distances between the expected and the estimated eye positions. To make the distance independent of scale of the face in the image and image size, it is normalized by dividing by the distance between the expected eye centers as $M_e = \frac{max(d_l,d_r)}{s} < T$, where d_l and d_r are the maximum distances between the manually labeled eye centers (between the true eye centers) and the eye centers found by the algorithm (estimated positions), s is the distance between the two manually labeled eye centers and T is the threshold used to declare a successful detection. If M_e is smaller than T = 0.25, the detection is correct. The Fig. 9 depicts relative error against successful detection rate. Using our proposed IGE filter, the successful detection is up to 93.3% at $T = 0.25$. A proof of robustness of our proposed IDE is shown in Fig. 8 and Fig. 10. By using IGE filter, eye regions are detected successfully in different illumination condition, scale and face expression and no matter that have eyeglasses and/or closed eyes or not.

6. CONCLUSION

In this paper, we have presented a novel efficient filter named Isotropic Gaussian Energy (IGE). Our proposed IGE filter is constructed by curvature and edge information at different kernels. To prove the usefulness of the proposed IGE filter, we have applied it to deal with eye detection. The experimental results on two databases, i.e. FRGC and MBGC, show that our proposed IGE filter successfully solves with eye detection no matter whether face image are in different scale, illumination and expression where eyes are closed or opened.

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