A New High Precision Eye Center Localization Technique

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Introduction

- Eyes represent the most distinctive features of the human face, while their position and movements are a significant source of information about the cognitive and affective state of humans.
- Precise eye center localization constitutes a challenging problem in many human-computer interaction applications.
- An automatic method is introduced for the precise eye center localization, based on a modified version of the Fast Radial Symmetry Transform[1].
- Experiments performed in two publicly available face databases, where there is a wide variety of ages, ethnicities, poses, lighting conditions, shadows, presence of occlusions (hair, glasses) and reflections.
- The results demonstrate the superior performance and enhanced accuracy of this technique against the state-of-the-art methods.

Proposed Method

The proposed method consists of the following steps (Fig. 1):

- Firstly, the face is detected and the two eye Regions Of Interest are selected.
- An edge-preserving filter is applied to enhance the circular shape of the eyes and separate them from the skin.
- Then, a modified Radial Symmetry Transform (RST)[1] is used to localize the eye centers. Specifically, its magnitude component results from the red color component of the original image while its orientation component from a properly filtered version of the original one. Finally, the superposition of their normalized counterparts denotes the position of the eyes centers.

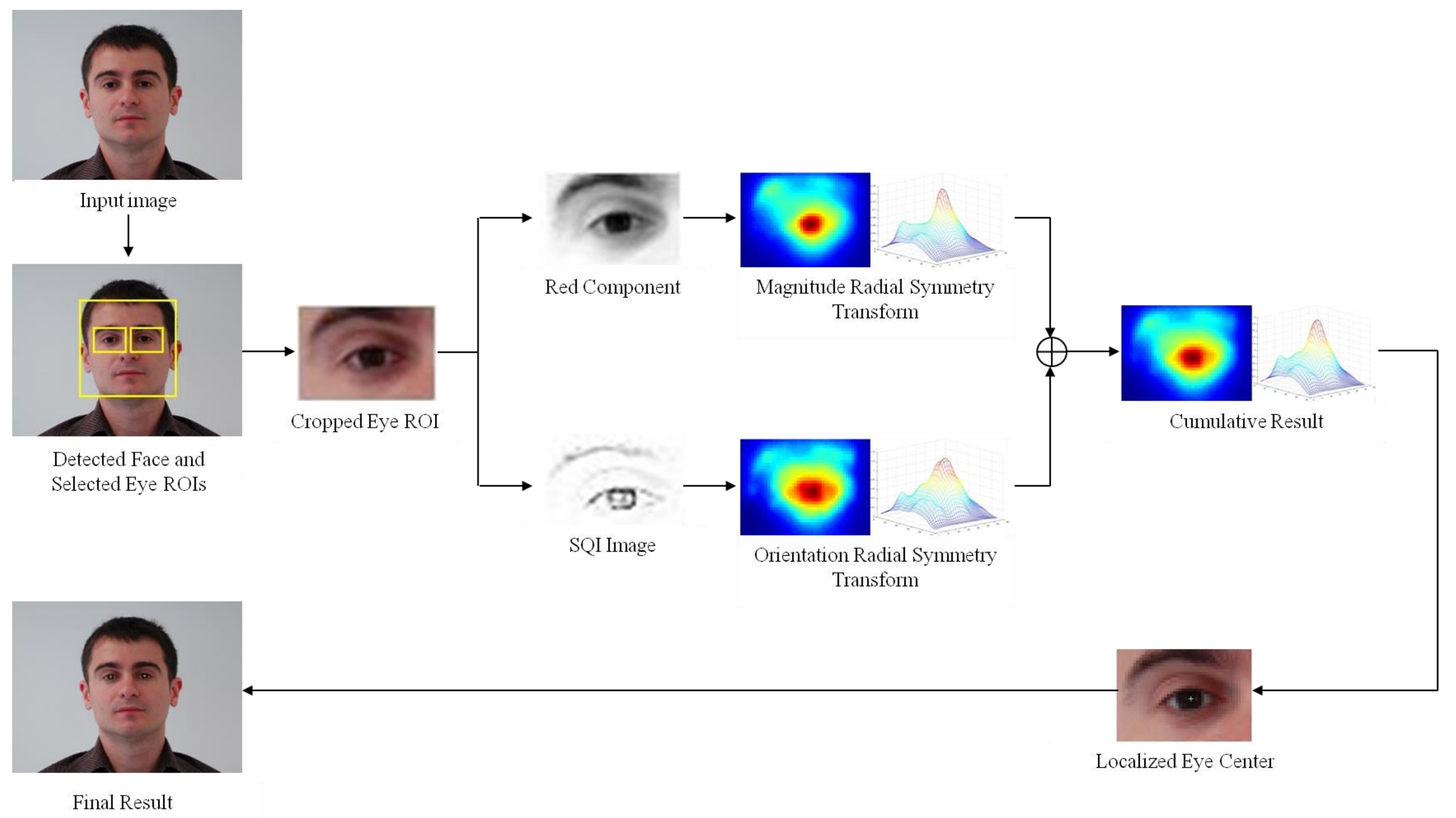

Fig. 1: Overview of the stages of the proposed system.

Edge Preserving Filtering

➢ Self-Quotient Image (SQI)

- **Observation**: Illumination is considered as one of the main limitations in the eye localization problem.
- **Goal**: SQI aims to construct a lighting invariant representation of the image which can effectively removes the shadow for any type of lighting sources.
- **Proposal**: The use of the SQI that is defined as the ratio of the input image and its smoothed version, i.e.:

$$Q(x) = \frac{I(x)}{I_\sigma(x)} \quad , \quad \text{where:} \quad I_\sigma(x) = I(x) * G_\sigma(x)$$

➢ Denoising Scheme

- **Observation**: SQI suffers from noise because of the division operation.
- **Goal**: The elimination of this undesirable amplification of the noise.
- **Step 1**. A sigmoid correction is applied to the SQI to suppress the noise:

$$T(x) = S\left(Q(x)\right) \quad , \quad \text{where:} \quad S(x) = \frac{1}{1+e^{-a(x-x_0)}}$$

- **Step 2**. A convolutional Gaussian kernel is used to smooth the image:

$$Q_f(x) = T(x) * G_{\sigma'}(x)$$

Fig. 2: Face images with strong illumination distortions and their shadow-free results

Modified Radial Symmetry Transform

- **Observation**: Symmetry constitutes one of the primary properties of the eyes.
- **Proposal**: Separation of the RST into two parts and exploit the Red component and the SQI image to precisely detect the eye centers.
- **Definition**: The affected pixels are determined based on the gradient direction:

$$p_{affected}(r) = p + round\left(\frac{\nabla I(p)}{\|\nabla I(p)\|_2} r\right)$$

➢ Magnitude Radial Symmetry Transform

- **Goal**: Exploit the enhanced contrast existing between the eyes and the skin.
- **Proposal**: Selection of the Red component only to apply the Magnitude RST.
- **Definition**: For each radius, a "Magnitude Projection Image" is constructed:

$$M_r(p_{affected}) = M_r(p_{affected}) + \|\nabla I(p)\|$$

The contribution is convolved with a Gaussian kernel and summed:

$$S_M = \sum_{r \in N} (M_r * G_r)$$

➢ Orientation Radial Symmetry Transform

- **Goal**: Exploit the shadow-free image from the edge-preserving filtering.
- **Proposal**: Application to the SQ Image and counting only on the orientation of the gradient to distinguish the eye shape.
- **Definition**: For each radius an "Orientation Projection Image" is constructed:

$$O_r(p_{affected}) = O_r(p_{affected}) + 1$$

The contribution is convolved with a Gaussian kernel and summed:

$$S_O = \sum_{r \in N} (O_r * G_r)$$

➢ The optimization problem

- The location of the eye centers results from the solution of the problem:

$$p^* = \arg\max_p (S_{M,norm} + S_{O,norm})$$

Parameters Specification

- **Selection of the set of radii**: It is selected based on the expected iris size in relation to the face dimensions:

$$r_{\min} = \max\left\{\frac{FaceWidth}{60}, 3\right\}, \qquad r_{\max} = \frac{FaceWidth}{6}$$

Experimental Setup

- The performance of the proposed method is evaluated in two publicly available face databases: **MUCT** (3755 color images, **BioID** (1521 gray-scale images).
- **Definition**: The normalized error, quantifying the worst eye estimation:

$$e = \frac{\max\left(\|\tilde{C}_L - C_L\|_2, \|\tilde{C}_R - C_R\|_2\right)}{\|C_L - C_R\|_2}$$

Experimental Results

1. The proposed method achieves high accuracy and robustness in localizing the eye centers (Fig. 3).
2. This method deals successfully under the most challenging circumstances, including shadows, pose variations, occlusions by hair or strong reflections, out-of-plane rotations, and presence of glasses (Fig. 3).
3. The contents of the Tables 1, 2 provide supporting evidence of the superior performance of the proposed method.
4. Points with e≤0.25 belong to a disk with its center located to the eye center and its periphery to the eye corner, points with e≤0.1 belong to the disk of the iris while points with e≤0.05 belong to the pupil area.

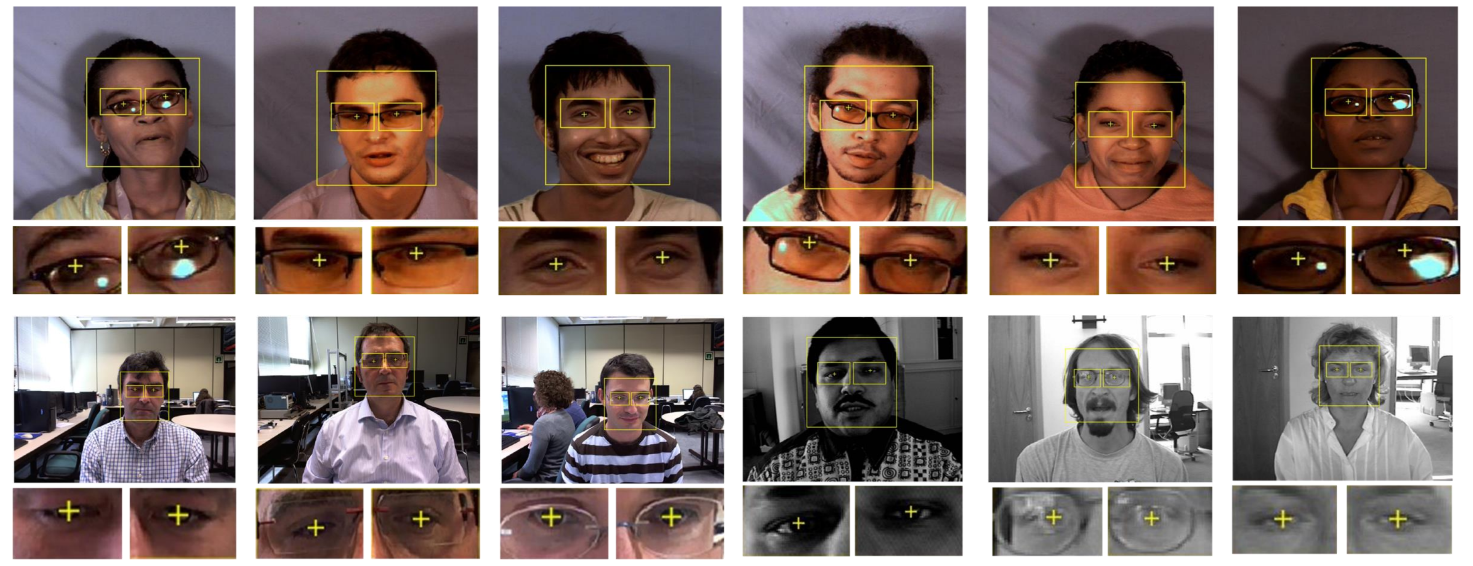

Fig. 3: Our method localizes precisely the eye centers under challenging conditions

Method	Accuracy (%)		
	e≤0.05	e≤0.1	e≤0.25
Proposed	**94.43**	**98.53**	**99.62**
Skodras[3]	92.9	97.2	99.0
Timm[4]	78.6	94.9	98.6
Yang[5]	81.6	89.5	94.5
Valenti[6]	63.1	76.7	94.1

Table 1: Accuracy vs normalized error in MUCT

Method	Accuracy (%)		
	e≤0.05	e≤0.1	e≤0.25
Proposed	**87.10**	**98.00**	**100**
Valenti[6]	86.1	91.67	97.87
Timm[4]	82.5	93.4	98.0
Leo[7]	80.7	87.3	94.0
Cristinacce[8]	57.0	96.0	97.1

Table 2: Accuracy vs normalized error in BioID

Conclusions

- A new, fully automatic, non-intrusive eye center localization method is proposed, based on a modified version of Radial Symmetry Transform.
- The proposed technique combines simplicity with high precision to provide accurate localization under the most challenging circumstances.
- This method was tested among the most challenging face databases and outperformed in accuracy the compared state-of-the-art techniques.

References

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