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A new illumination preprocessing method for face recognition

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Abstract: Differences in illumination of the same face can defeat simple face recognition systems, yet most methods that compensate are too difficult to implement. Local quotient image (LQI) is an efficient illumination preprocessing method for face recognition systems. An illumination model and a face model were developed, and their use in the new method was analyzed in detail. Analysis of the method's computational complexity showed it to be efficient. Experimental results on Yale Face Database B showed that the method can effectively eliminate the effects of differences in illumination and provides considerable improvement in recognition rates.

Keywords: face recognition; illumination preprocessing; local quotient image; illumination model

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Face recognition has become one of the most successful applications of image analysis and understanding as a result of significant research work in the last decade[1-2]. However, variations in the quality of images heavily affect the performance of current face recognition systems. Experiments done on the Facial Recognition Technology (FERET) database and the Face Recognition Vendor Test 2000 (FRVT2000) tests showed that variations in illumination are among the bottlenecks for a practical face recognition system[3]. Face appearance can change dramatically due to illumination changes, and "the variations between the images of the same face due to illumination are almost always larger than image variations due to change in face identity"[4]. Fig. 1 shows the same person under different illumination conditions in Yale Face Database B[5].

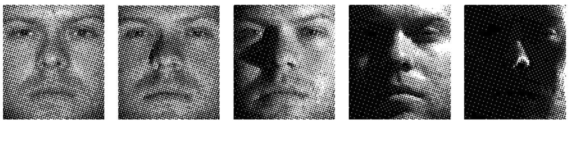

Fig. 1 The same person under different illumination conditions in Yale Face Database B

Many methods have been proposed to deal with the illumination problem, including illumination cones[5], symmetric shape-from-shading[6], quotient image[7], gamma intensity correction[8], self quotient image[9], eigenphases[10], histogram equalization and logarithm transforms[11]. Good results have been reported by all these methods. However, some of these methods require other images of the same person under different illumination conditions and some have a comparatively high computational complexity which makes them impractical. For example, Shape-From-Shading, Quotient Image, Illumination Cones all require more than one image of the same person, while Self Quotient Image and Eigenphases have comparatively high computational complexity. Histogram equalization and logarithm transforms are easy to implement and don't require other images, but their performance is not good enough.

A novel illumination preprocessing method for human face recognition was proposed and is discussed in this paper. Two major advantages of the method are that it has a low computational complexity and requires no other images.

The remainder of this paper is organized as follows. Section 1 introduces the human face model and illumination model adopted in this paper. Section 2 describes the proposed method in detail. Sections 3 and 4 show the experimental results and conclusions.

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1 Human face model and illumination model

In this paper, we adopted the human face model and illumination model proposed by Xie and Lam[12]. Faces can be regarded as Lambertian surfaces, and the face image can be described by the product of the albedo and the cosine angle between a point light source and the surface normal:

$$I(x,y) = \rho(x,y) \cdot \boldsymbol{n}(x,y) \cdot \boldsymbol{s}. \quad (1)$$

where $I(x,y)$ is the intensity value of the pixel at (x, y) in the image. $0 \leqslant \rho(x,y) \leqslant 1$ is the corresponding albedo, $\boldsymbol{n}(x,y)$ is the surface normal direction, and $\boldsymbol{s}$ is the light source direction (point light source) and whose magnitude is the light source intensity[7].

A face model widely used in computer graphics applications was adopted for this paper. We treated a human face as a combination of a sequence of small, flat facets[13-14]. Fig. 2 shows a human face overlaid with this corresponding CANDIDE-3 model[15], a combination of a sequence of triangular facets.

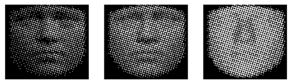
Fig. 2 CANDIDE-3 model of a human face

In this paper, we addressed the illumination problem for face recognition under the following assumptions: The area of each facet W is small enough to be considered a planar patch and for each point $(x,y) \in W$, the surface normal direction $\boldsymbol{n}(x,y)$ is considered to be a constant. In addition, the light source is assumed to be directional; the light source direction $\boldsymbol{s}$ is also almost constant within W.

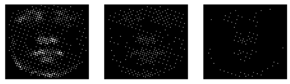
The appropriateness of this assumption has been proven by DU BO[16]. In that work, 9 different illumination environments (including several environments illuminated by spotlights) from Debevec (http://www.debevec.org/Probes) were used on face models to generate face images under different illumination conditions.

We then computed the illumination variations within a small facet W on each face image. The results are shown in Fig. 3. The images in the last row of Fig. 3 are almost all black, which means that illumination difference within a small facet W is almost zero. We can see that the illumination conditions almost remain constant within a small facet. See Ref. [16] for details.

(a) illumination environments



(b) face images under different illumination environments



(c) illumination variations within each facet

Fig 3 (a) illumination environments (b) face images under different illumination environments (c) illumination variations within each facet

2 Local quotient image method

Our method applies a filter to each pixel of the face image, and obtains a new image which is insensitive to illumination.

In our method, a small and flat facet W is represented by a filter of size $n \times n$. The filter $W(x,y)$ is centered on the pixel x,y. We define

$$I'(x,y) = \frac{I(x,y)}{\max\limits_{(u,v) \in W(x,y)} I(u,v)}. \quad (2)$$

where $I(x,y)$ is the intensity value of the original face image, and $I'(x,y)$ is the intensity value after processing.

Based on the assumption made in the prior section, the surface normal direction within W is a constant, that is, $\boldsymbol{n}(x,y) = \boldsymbol{n}(u,v)$ and the light source direction $\boldsymbol{s}$ is almost constant within $W(x,y)$. And we get:

$$I'(x,y) = \frac{I(x,y)}{\max\limits_{(u,v) \in W(x,y)} I(u,v)} = \frac{\rho(x,y) \cdot \boldsymbol{n}(x,y) \cdot \boldsymbol{s}}{\rho(u,v) \cdot \boldsymbol{n}(u,v) \cdot \boldsymbol{s}} = \frac{\rho(x,y)}{\rho(u,v)}. \quad (3)$$

Obviously, $I'(x,y)$ is irrelevant to illumination and reveals the nature of the face image. This means that, after processing, a new image which is insensitive to illumination is obtained. This new image is called Local Quotient Image (LQI), and the range of each pixel in local quotient image is [0,1], which can add benefit when used in the recognition algorithm. Fig. 4 shows sample human faces and their corresponding local quotient images.

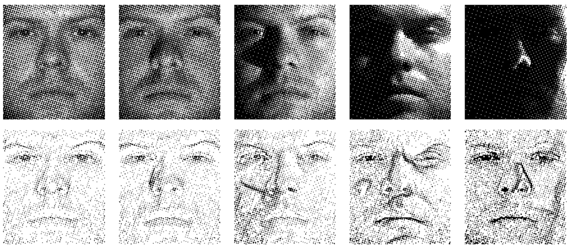


Fig. 4 Human faces and corresponding local quotient images

What's more, LQI method is an efficient illumination preprocessing method. If the size of a given face image is $M \times N$ and the filter size is $n \times n$, the computational complexity for preprocessing an image using LQI method is $O(MNn^2)$. It's better than most methods proposed so far.

3 Experimental results

In order to evaluate the performance of the proposed illumination preprocessing method, we tested it on Yale Face Database B[5], which is a public face database specializing in illumination and pose variations in face recognition. All images are cropped and normalized to a size of , and are aligned based on the two eyes. Since this paper mainly deals with the illumination problem, we only choose the 64 frontal images captured under 64 different lighting conditions for each of the ten subjects. Example images of one person in frontal pose are shown in Fig. 5. The images are divided into five subsets according to the angle that the light source direction makes with the camera axis-Subset 1 ($\alpha < 12°$), Subset 2 ($20° < \alpha < 25°$), Subset 3 ($35° < \alpha < 50°$), Subset 4 ($60° < \alpha < 77°$), and Subset 5 (Others). See Ref. [5] for details.

In our experiments, Subset 1 (7 images for each person) is chosen as the gallery and each of the images in the remaining 4 subsets is matched to the images in the gallery so as to find a best match.

Since our goal is to evaluate the performance of proposed illumination preprocessing methods, the distance measurement and classification method are not important for us. Therefore, the simplest normalized correlation[17] was exploited as the distance measurement. In the normalized correlation method, the similarity between two images $\boldsymbol{I}_0$ and $\boldsymbol{I}_i$ is defined as:

$$\Phi(\boldsymbol{I}_0, \boldsymbol{I}_i) = \frac{\boldsymbol{I}_0 \boldsymbol{I}_i}{\| \boldsymbol{I}_0 \| \cdot \| \boldsymbol{I}_i \|}. \qquad (4)$$

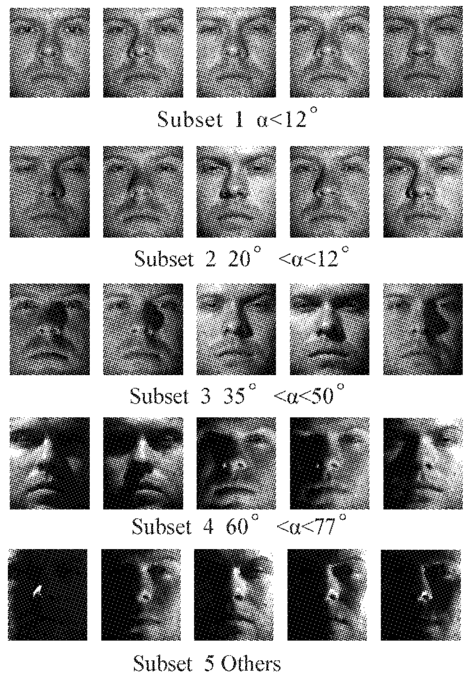


Fig. 5 Example images of the first subject, divided into 5 subsets

And in our experiments, classification was performed using the nearest neighbor classifier. The LQI method was compared with two traditional simple methods: histogram equalization (HE) and logarithm transforms (Log). In the experiment, we set the block size at . The recognition rates are illustrated in Table 1. From the experimental results we can see that our method can effectively eliminate the effects of illumination and the average recognition rate is improved to 99.47%.

Table 1 Experimental Results /%

Method	Recognition Rate				Average
	Subset2	Subset3	Subset4	Subset 5	
None	100	94.17	42.14	25.26	59.65
HE	100	92.50	40.00	50.00	67.02
Log	100	89.17	54.29	62.63	74.04
LQI	100	100	98.57	99.47	99.47

4 Conclusions

An efficient illumination preprocessing method for face recognition under varying lighting conditions was proposed. The method regards the faces as Lambertian surfaces, and treats faces as a combination of a sequence of small and flat facets. This system is widely used in computer graphics applications. A local quotient image method was applied to the face image pixel by pixel. The images obtained after preprocessing were supposed to be invariant to illumination variations. The experimental results demonstrated the effectiveness of our method.

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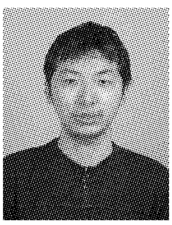
Biographies:



Sheng Gan obtained his bachelor's degree in Computer Science in 2006 from Beijing Normal University. At the same time he also obtained another bachelor's degree in English Literature. He won the first prize in Mathematics Contest for Beijing College Students in 2004. He ranks among the top 5% in his department. His field of interest is Computer vision and Pattern recognition.