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# Illumination compensation for face recognition using adaptive singular value decomposition in the wavelet domain

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ABSTRACT

Lighting variations are a challenge in face recognition. To overcome this problem, this paper proposes a novel illumination compensation method called adaptive singular value decomposition in the 2D discrete wavelet domain (ASVDW) to enhance face images. First, an efficient brightness detector based on the blue pixel values of the red green blue (RGB) color channels is used to classify the color face image into dark, normal, or bright before applying the corresponding Gaussian template. The RGB color channels of the face image are then transformed to the 2D discrete wavelet domain. The frequency subband coefficients of the three color channels are automatically adjusted by multiplying the singular value matrices of these frequency subband coefficient matrices with their corresponding compensation weight coefficients. An efficient image denoising model is then applied, and a 2D inverse discrete wavelet transform is applied to obtain the ASVDW-compensated color face images without the lighting effect. In addition, a region-based ASVDW method (RASVDW), which entails the application of the ASVDW algorithm in four regions of an image, is introduced to reduce the computing time. Experimental results validate the efficiency of the proposed methods.



## 1. Introduction

In recent years, face recognition has been studied in the domains of pattern recognition, computer vision, and machine learning. However, several factors that influence the performance of face recognition systems, such as head pose variation, illumination variation, and facial expression, remain to be resolved. Illumination variation is the most critical factor that alters facial appearances: different illumination conditions can alter facial appearances in images. In the real world, nonuniform light such as polarized light, side light, and high light cause over-bright, over-dark, or shadow regions in face images. Numerous methods have been proposed to overcome the problem of illumination variation, all of which can be grouped into three major categories: illumination-invariant feature extraction, modeling face images as linear space, and illumination compensation or normalization.

The first category involves methods for obtaining the representative features of facial images by extracting the illumination-invariant components. In [4], the illumination of a given image was initially enhanced using a normalized log

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function, and the image was decomposed through a double-density dual tree complex wavelet transform (DD-DTCWT). The image was then reconstructed by adopting an inverse DD-DTCWT after performing a thresholding operation on the high-frequency subband. A maximum filter was used to further enhance the reconstructed image. Finally, a feature vector mask was employed to obtain the illumination-invariant image, which was used as a feature for face representation. Cao et al. [9] considered the correlation between neighboring wavelet coefficients and extracted an illumination-invariant trait using a NeighShrink denoising model to estimate the illumination components. They then utilized different processing models to train and test the images. The test process involved using only approximation coefficients, whereas the training process entailed applying a wavelet-based denoising model on detail coefficients. Goh et al. [18] attempted to extract illumination-invariant components by first transforming a facial image in the logarithm domain to the wavelet domain and then setting the illumination component (approximation coefficients) to zero. Similarly, Hu [25] and Zhang et al. [48] used a discrete wavelet transform (DWT) in the logarithm domain to extract the illumination discontinuities in the detail subbands by using a denoising model and then obtained the illumination invariants by using a multiscale reflectance model. Chen et al. [11] presented a logarithmic total variation model that can factorize a single facial image to obtain the illumination-invariant facial structure. Fan and Zhang [16] first used homomorphism filtering to reduce the effect of illumination and then obtained an illumination-normalized facial image by enhancing the contrast through histogram equalization (HE). Based on the assumption that the reflectance component changes abruptly whereas the lighting source changes slowly, Goh et al. [19] employed DWT to remove unwanted low-frequency illuminations and then used the local binary pattern histogram of the original image to enhance the test image. Finally, the wavelet fusion technique was applied to obtain the illumination-invariant images. Similarly, Zhang et al. [49] defined an illumination-insensitive measure—the ratio of the horizontal and vertical gradients—and obtained illumination-insensitive images by computing the arctangent of the illumination-insensitive measures. Wang et al. [43] and Wu et al. [47] have realized illumination-insensitive representations for face images using Weber's law. In summary, the log-transformation used in most of these methods can lead to the loss of dominant information because it is a nonlinear transform. Furthermore, in these studies, several threshold parameters were applied that were heuristically established in the models.

The second category (i.e., modeling face images as linear space) includes methods that model the faces of the same person under varying illumination conditions as a low-dimensional linear subspace in the face space. Jiang et al. [28] used nine spherical harmonic bases called harmonic images to span the facial illumination subspace and then compensated the original image with its inverse illumination condition. In [5,17,30], the set of images of a person in a fixed pose under all possible lighting conditions was used to form a polyhedral cone called the illumination cone in the image's space, and this cone could be approximated through a low-dimensional linear space. Although these methods can model the illumination variations, they require a large amount of training data and entail more constraints when used in real applications.

The third category (i.e., illumination compensation or normalization) includes illumination compensation or normalization-based methods for illumination normalization in face images captured under varying lighting conditions. HE [20] is a basis method for adjusting the contrast of images. However, the images that are processed using HE under varying lighting conditions may be uneven. This is because HE is a global processing technique. Pizer et al. [34] introduced adaptive histogram equalization (AHE) that computes several histograms—each corresponding to a distinct section of the image—to redistribute the image's brightness values. However, AHE has a tendency to overamplify noise in relatively homogeneous regions of an image. Shan et al. [38] proposed a region-based HE and gamma intensity correction method for correcting the overall brightness of the face images to predefined "canonical" face images. Moreover, they indicated that dividing the polarized light into several subimages is necessary. Savvides and Kumar [36] used LT to obtain stable face images captured under various lighting conditions for face verification. However, these methods were processed in the spatial domain and do not work effectively with images under strong lighting conditions. Chen et al. [11] used a discrete cosine transform (DCT) to compensate for illumination variations in the logarithm domain. Based on observations that illumination variations mainly lie in the low-frequency band, an appropriate number of DCT coefficients was truncated to minimize the variations under different lighting conditions. Using a discrete Fourier transform, Savvides et al. [37] performed a principal component analysis (PCA) in the phase spectrum of the face images in the Fourier domain, while fixed the magnitude spectrum. Similarly, Heo et al. [21] first modeled the phase information of face images in the Fourier domain to represent faces and then applied support vector machines to claim an identity using different kernel methods; none of the information in the magnitude spectrum was used. By contrast, Choi and Jeong [13] proposed a shadow compensation method that involves fixing the phase spectrum and substituting the magnitude spectrum of the face image by the mean of its magnitude spectrum and the auxiliary magnitude spectrum. The auxiliary magnitude spectrum was computed by averaging the magnitudes of the face images from the database. Du and Ward [15] normalized the illumination of face images by first using DWT to decompose the face images; then, HE was applied to the approximation coefficients, and the detail coefficients were enlarged by multiplying each element in the detail coefficient matrix with a scale factor greater than one. Although these methods can improve face recognition performance, the elimination of some components results in information loss.

Although most researchers have attempted to resolve the illumination variation problem in grayscale face images, several methods have been proposed for color face images. Torres et al. [42] indicated that color information expressed in certain color spaces may be useful in face recognition. Hsu et al. [24] introduced the "reference white" pixel concept and proposed a lighting compensation technique that uses the "reference white" concept to normalize color appearance. Demirel and Anbarjafari [14] used singular value decomposition (SVD) to compensate for the lighting to reduce the effect of the illumination on color images. However, in this method, only one Gaussian template was applied for the three red green blue (RGB) color